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Evaluation of the PGSF's Output Area 6:

Fishing and Aquaculture Industries

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Executive Summary

Background

The fishing and aquaculture sector:

- includes a seafood industry which is currently New Zealand's 4th largest export earner and employs about 11 000 people
- has strong Maori interests including customary fishing rights, supports large numbers of recreational fishers, and is increasingly a tourist attraction
- is regulated by central and regional government agencies
- competes in a global market with competitors who are heavily subsidised by their governments, and must overcome substantial trade barriers
- uses an environment about which very little is known, which has an area several times greater than our land area, and is affected by agricultural and other human activity as well as fishing.

Change in the Seafood Industry

There has been considerable change in the seafood industry since 1993/94:

- Commercial fishing has pushed out into new areas, fishing at depths that until recently were inaccessible, catching species that were previously unknown and which live in habitats about which we had no prior knowledge.
- About 90% of the New Zealand catch is now exported, earning about $1.2 billion.
- Most of our known fish stocks are considered to be fully developed - increases in output are coming through aquaculture, currently about 11% of exports.
- Seafood products have increased in quality and value through improved harvesting, processing and chilling regimes. These innovations have made New Zealand product more competitive and enabled it to retain market share despite recent market downturns.
- The industry has become much more sophisticated in terms of its ability to perform and also its ability to absorb and utilise new knowledge.

  It has consolidated to the point that ten companies now take 90% of the total catch, and the three largest have become significantly more capital intensive.

  Two of these three have their own research units, which interact closely with science providers and supplement their own spending on research with TBG projects.
- The industry has formed a number of representative stakeholder groups, some of which facilitate the development of research strategies and are able to influence the science providers in order to have their research needs met.

  The proactive stance taken by some of these groups improves communication between industry and science providers, and increases the likelihood that research outcomes will be taken up successfully by their members.

  Smaller companies improve through industry training, hiring of staff from the bigger companies, or by using products and services from suppliers to the industry who have themselves learned from the bigger companies.

Research

There are a variety of sources of funding for research:

– research into wildstock fishery sustainability currently costs about $15 million, of which 75% comes from the seafood industry through a levy, and 25% from the Government, all managed by the Ministry of Fisheries

– the industry funds research and development from its own resources, to a level estimated at $11 million in 1993/94

– the PGSF has increased funding from $3.8 million in 1993/94 to $7.4 million in 1997/98, an increase averaging 18% per annum.

  NIWA is the principal science provider, but the focus of the PGSF has shifted away from NIWA's core activities, and its share has dropped slightly from 57% to 51%. Crop&Food currently receive 22% of the funding, and Cawthron about 13%.

  The PGSF initially emphasised the development of aquaculture and the extension of the shelf life of seafood products, and these topics still take 32% and 14% respectively of available funding. The remainder is allocated to new topics such as toxic algae (20%) and the sustainability of shellfisheries (18%).

  Research into the environmental impact of fishing is funded principally by the Ministry of Fisheries.

Value Created by PGSF Supported Research

Considerable value has been created through use of the PGSF in this Output:

- significant **economic** benefits are being achieved:
  - new industry sectors have been established, currently earning $120 million p.a. in revenues, and several more are developing, with the potential of earning another $250 million p.a.
  - quality enhancement has enabled the preservation of markets currently worth $215 million p.a., during a world-wide downturn, and has contributed to the increasingly strong image of New Zealand product in our principal markets
  - quantifiable reductions in public costs of $2.5 million p.a. have been achieved through toxic algae programmes
  - the industry has been protected from the imposition of non-tariff trade barriers in its major markets
  - the industry has become a substantial employer in rural areas, and has generated considerable related economic activity
  - considerable, and in many cases world-leading, science capability has been created in New Zealand, which has enabled science providers to offer additional services and in some cases to license products for commercial application.

- **environmental** benefits are being obtained:
  - the management of fisheries has been improved through better information and performance indicators, benefiting regulators and users; a better understanding of the inter-dependencies within our marine ecologies; and a better understanding of the effect of fishing on the carrying capacity of the ecology
  - the environmental impact of waste is being reduced, through methods of realising value from fish wastes and reducing wastage levels in general
  - research into toxic and noxious algae has resulted in a cheaper and more ethically acceptable testing regime for the industry and the public.
- **social** benefits are being obtained:
  - Maori groups benefit directly - Maori own about 40% of the industry, and represent a high proportion of employees. Growth in the industry will increase Maori employment and overall well-being in rural areas
  - public health has been improved as a result of research into toxins.

Conclusions

This review concludes that:

- Government objectives for the use of the PGSF have been met in this Output
- Benefits have been achieved well in excess of costs
- While funding in this Output has been increased, the industry feel that the level is still very low in comparison with the funding levels of land-based industries
- The nature of research supported by the PGSF is a reasonable match with the needs of the various interest groups, but there are areas which should be made more of a priority for the near future
- The innovation process has improved considerably in the seafood industry, but there are actions which could improve it further
- There are issues relating to intellectual assets and the realisation of commercial opportunities arising from research programmes which should be dealt with
- industry has become more aware of the value of research and development, and will increasingly desire and be able to carry out its own research, either directly or by contract with science providers. Its need for basic research will become more focused and articulated, and the value created by the PGSF will continue to be enhanced.

1. The Context in which Research is Carried Out

In order to review the effectiveness of research in Fishing and Aquaculture Industries, it is important to understand the context in which it is being carried out. This section reviews the global and the local seafood industry, the ability of the latter to absorb knowledge, the extent and allocation of the funds made available for research during the period under review, and the science providers themselves.

1.1 The Global Seafood Industry

Reported global production of seafood was 113 million tonnes in 1995. NZ has the 5th largest economic zone in the world, but is ranked 30th in terms of seafood production - our exclusive economic zone produces about 0.7 million tonnes of seafood in 1997, worth about NZ$1.2 billion. This made the seafood industry NZ's 4th largest export earner in that year, producing about 6% of NZ's exports by value (similar in size to wool exports).

Characteristics of the global industry include:

- relatively stable volumes of wildstock fish production, but declining value, as lower value fish are caught in place of over-exploited higher value fish.
- production from aquaculture increasing at about 10% per annum, so that aquaculture now provides more than 25% of the total global supply of fish used for food.
- relatively low value use of the catch - of the total supply of fish, about 30% is reduced to fish meal (animal feed) and fish oil.
- high rates of discard and spoilage - it has been estimated that about 25% by weight is discarded before the catch is reported, and that 4% of the reported catch is lost post-harvest due to spoilage.[1] In the New Zealand context, this loss could potentially have a value of about $0.3 billion a year.
- heavy subsidisation and over-capitalisation - it has been estimated that world-wide subsidies are in excess of $100 billion, and as a result fishing fleets are 2 or 3 times larger than that needed to harvest the global catch.[1] These subsidies distort the market and depress prices, therefore reducing the returns available to the NZ industry, which is no longer subsidised.
- protection of local markets - through a variety of tariff and other barriers to trade. Seafood is a mostly commodity, with prices driven by supply and demand (although New Zealand is attempting to differentiate on quality).
- over-exploitation of commercial species. The NZ resource is now managed through a rights-based system that is expected to protect the long-term value of our resource. This system is supported by research into sustainability paid for largely by a levy on the industry (refer Section 1.3).

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[1] *State of World Fisheries and Aquaculture*, Food and Agriculture Organisation of the UN, 1995

1.2 The NZ Seafood Industry and Other Stakeholders

The NZ seafood industry has changed in the last twenty years:

- It used to use small boats - it now has enough deepwater capacity to land 65% of the larger finfish catch. Foreign vessels licensed to NZ companies catch the remainder.
- It used to primarily fish inshore waters - the inshore fisheries are now in economic crisis, and fishing now takes place in deeper offshore waters.
- It used to sell most of the catch in local markets. About 90% of the catch is now exported.
- Recent production increases have come through aquaculture, which has expanded rapidly - mussel and salmon farming now earn about $120 million in exports, or about 11% of total seafood sales. Our wildfish stocks are now considered to be fully developed.
- It has reduced its reliance on Japan, the USA and Australia by building new markets in Asia and Europe, and now exports to more than 80 countries.
- The latest GATT round led to reductions in import tariffs affecting NZ exports, but the local seafood industry in most of our markets remains protected by a variety of trade, phytosanitary and other barriers. The increased range of countries exported to means that NZ industry must demonstrate that it meets an increasingly wide range of requirements.
- It has products that have improved considerably in quality through better harvesting, processing and chilling regimes. These improvements have increased the value of the product, made NZ product more competitive, and enabled the industry to retain market share despite recent market downturns.

The seafood industry now includes approximately:

- 2 500 commercial fishers, including quota and permit holders
- 250 fish processors
- 300 marine farmers.

About 40% of the industry is now owned by Maori interests, and the industry employs about 11 000 people.

Other stakeholders have an interest in the marine environment, including:

- iwi (about 60)
- recreational fishing organisations (about 30, representing at least 30 000 individual fishers)
- environmental and tourism-related groups (about 150)
- government agencies (about 30, including central and local government)
- suppliers of goods and services to the industry.

With the exception of the government agencies, these groups have not been making extensive use of available research funds.

1.3 Policy, Legislative and Regulatory Issues

In 1986 the government introduced a quota management system in an attempt to limit misuse and overexploitation of fish stocks. Under this system, a total allowable catch is set annually for each stock and individual catch entitlements are defined by quota, which are transferable between fishers.

This system has proved an effective means of limiting catches from fish stocks, and the use of transferable quota encourages greater economic efficiency in harvesting, thus providing disincentives to over-capitalisation.

The Government provides funds through Vote: Fish to support the quota management system. The majority of these funds are recovered by levy from the industry, and the system is managed by the Ministry of Fisheries, which allocates funds to a variety of research programmes associated with quota management and the impact of fishing on the marine environment. Current proposals for 'co-management' will allow the industry to take a more active role, responsible directly to the Minister, while also providing for the involvement of other interest groups such as iwi and recreational fishers.

The Fisheries Act 1996 has put further emphasis on sustainability, and has increased the demand for information on all aspects of fisheries and the marine environment. Some fisheries management responsibilities are in the process of being devolved to rights holders.

The industry is affected by various other legislation, particularly including the Resource Management Act 1992. Further legislation passed in 1998 tightened regulations affecting customary fishing by Maori groups, and is expected to reduce the incidence of abuse by recreational and customary rights fishers.

A number of fishing reserves have been established in an attempt to preserve and restore inshore fisheries.

1.4 The Ability of the Industry to Innovate

The ability of an industry to innovate relies on several factors, including:

- Strong capabilities in the industry for research and development
- Very good market feedback
- Strong communication and networking between key participants
- Effective industry co-ordination, leadership and representation
- An enhanced ability to absorb knowledge
- A vibrant and entrepreneurial culture
- Sufficient resources to support the effort involved
- Close involvement of specialist suppliers to the industry.

The industry has generally relied on science providers for research and development. The consolidation of the industry in recent years has, however, allowed the larger organisations to build an in-house capability as well, which has in turn enabled them to make better use of Technology New Zealand funding.

As a result, the industry's ability to create, absorb and apply knowledge has improved:

- The industry has become more sophisticated, both in terms of its ability to perform and also its ability to absorb and utilise new knowledge. It has consolidated to the point that ten companies now take 90% of the total catch, and the three largest have become significantly more capital intensive. Two of these three have their own research staff, who interact closely with science providers and supplement their own spending on research with TBG projects.

  The largest of the regional bodies also have their own research staff. These organisations have staff who can communicate directly with scientists, and who have built up close relationships with the researchers working in the areas of most interest to their organisations.

  The remaining groups have representative bodies but relatively little access to funding of their own. Recreational fishers and tourists who use the marine environment are not currently required to pay a levy on their activities - this lack of funds restricts their representative groups.

- The close links established by the larger organisations mean that the research delivered is more likely to be relevant and understood by end-users, and it is more likely that user organisations will benefit from the outputs of the research programmes.

  Other organisations, without in-house skills and science capability, must rely on more indirect means to obtain and absorb knowledge.

  These indirect means typically involve:

  – staff churn (staff taking knowledge from a top tier organisation to another as they change their employer)

  – suppliers of goods and services to the industry (who have learned from serving a top tier organisation, and apply that knowledge to other customers)

  – picking up information via trade journals or direct observation

  – staff gaining skills and knowledge via industry training organisations

  – being influenced by individuals (champions) in the industry with considerable mana, who demonstrate or recommend actions or products.

- A variety of stakeholder groups have been created in the seafood industry, generally representing fishers and marine farmers involved in a particular species, and generally under the umbrella of the Seafood Industry Council (SeaFIC). These groups create their own strategic plans, determine their research (knowledge) needs, and take proactive action to satisfy those needs. These groups will often also translate the research output into terms that their individual members are able to understand and apply.

  The proactive stance taken by the more successful of these groups (such as the Mussel Industry Council) has increased the likelihood that research outcomes will be taken up by individual member companies, and the groups are providing a mechanism for effective communication between scientists and fishers.

Where these groups are still ineffective, only the larger companies appear to benefit from science – the smaller companies slowly improve through industry training, hiring of staff from the bigger companies, or by using products and services from suppliers to the industry who have themselves learned from the bigger companies.

- SeaFIC is encouraging an awareness of product quality, and supports an industry training organisation (SITO). Training provided through SITO has now affected a significant proportion of staff employed in the industry, and the units offered are being rapidly improved in range and sophistication.

In order to obtain a more objective view on the industry's ability to absorb knowledge, organisations were surveyed to obtain information about their knowledge management awareness and practices. Responses indicated that:

- 57% of industry users recognised that knowledge was embodied in products and 45% that it was applied in their processes, but only 25% recognised staff as a knowledge-related asset
- 51% considered themselves as having a 'continuous learning culture', but 45% reported their knowledge assets being maintained 'informally'
- virtually no respondents reported using science journals as a source of knowledge. 62% relied on attendance at seminars, 57% used trade journals and 51% relied on direct interaction (collaboration) with science providers
- 60% regarded themselves as being well-equipped with the staff needed to absorb knowledge, 51% thought their networking was satisfactory, 30% regarded their information systems as sufficient for the purpose, but only 11% reported having enough funding to support acquiring knowledge
- 49% take no specific action to protect their knowledge-related assets, 30% reported a general awareness of the risks, and 30% reported monitoring taking place at Board level.

Government organisations surveyed displayed similar patterns:

- the majority use informal means to maintain their knowledge assets
- 79% attend seminars and 71% collaborate with science providers to obtain their knowledge
- they appear to be better resourced (64% reported being well-equipped with staff able to absorb knowledge)
- there is less emphasis on protecting knowledge-related assets.

Scientists continue to report via articles in peer-reviewed journals, where the peer review process remains a vital element in ensuring high standards and the credibility of science, and in developing personal reputations. They are increasingly using workshops, seminars, roadshows and popular articles to transfer knowledge to a wider group of end-users

1.5 Sources of Funding for Research

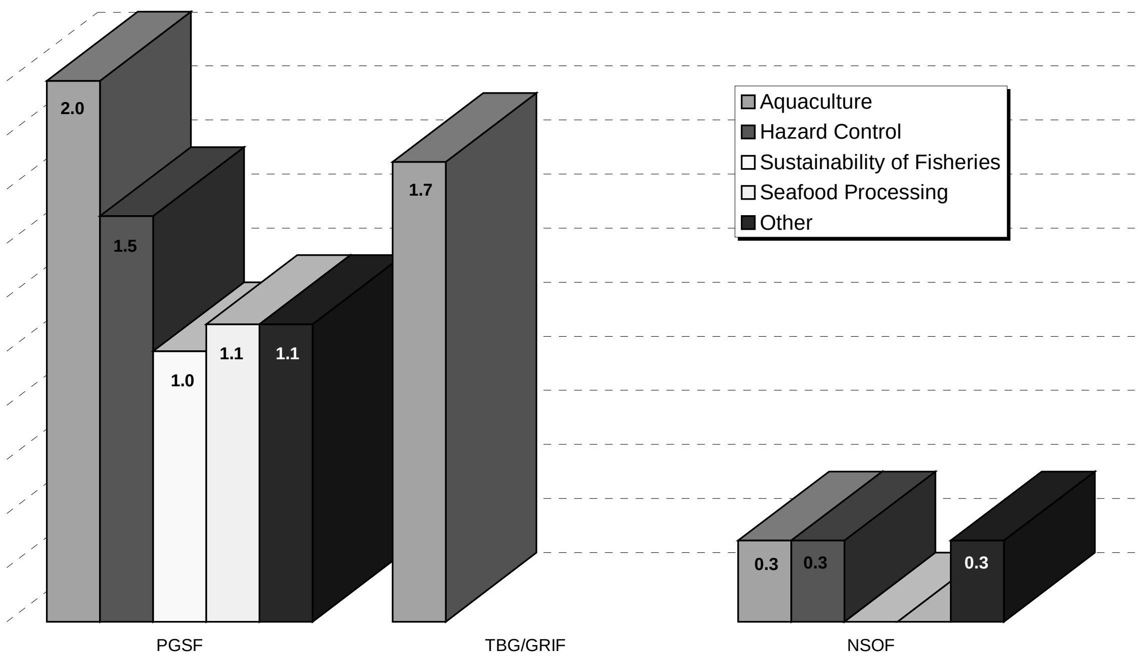
There are five main sources of research funding in the fishing industry:

- **Vote: Fish** provided $14 million in 1996/97, of which 79% or about $11 million was recovered from the industry via a levy. Some of this supports the Ministry of Fisheries itself, but the majority is spent on research programmes intended to ensure the sustainable utilisation of fisheries
- **industry** was estimated to have spent a further $11 million on its own research and development activity in 1994[2]. Part of this has been used in funding research from science providers under contract, and the remainder represents company funds devoted to in-house activity
- the **PGSF** provided about $7.4 million in 1997 for research in Output 6
- **TBG, GRIF, and related programmes** supported by Technology New Zealand were used to support research in Output 6 to a level of approximately $1.7 million in the 1997/98 round.
- **NSOF** has been applied to fisheries research totalling about $0.9 million in the 1997/98 period.

The smaller Conservation Sciences fund (administered by the Dept of Conservation) also has application to the marine environment.

Figure 1.1 shows the allocation of government funds for the 1996/97 year, using allocation categories developed for this report. A breakdown of industry research by these categories was not available.

Figure 1.1: Allocation of Public Funds (PGSF/TBG/NSOF, $ million, 1997)



Output 6 has attracted increasing funds from the PGSF since the 1992/93 bidding round. Total funding has increased from $3.8 million in 1992/93 to $7.4 million in the 1997/98 round, an average increase of 18% per annum (Figure 1.2).

[2] *Fisheries Research Survey*, prepared by Novatech for the NZ Fishing Industry Board, Dec 1994

1.6 Allocation of PGSF by Science Provider

Seven CRIs, two universities and one private organisation have been awarded PGSF contracts in Output 6 since the 1993 bidding round. A further three organisations (including one more CRI) have been involved in a subcontract capacity.

A summary of funding by provider is shown in Figure 1.3 overleaf, and a detailed list of programmes by provider is presented in Appendix 3. In summary:

- NIWA has attracted the majority of the funding in the Output. It remains the major player in aquaculture research, and has developed another stream of activity researching aspects of the sustainability of fisheries, complementing their work carried out in this area for MFish.
- Crop & Food have developed a centre of excellence in seafood processing, based in Nelson, which has attracted increasing funding over the period.
- Cawthron is the third provider with funding of any significance, researching aspects of aquaculture and toxic algae.

The Universities have attracted some funding, as have a few other CRIs, but there has been virtually no private sector research funded by the PGSF.

Of the 64 programmes funded during the period of this review, 20 (or 31%) involved sub-contracting of part of the research activity. Almost half of these involved Universities, primarily the University of Canterbury, and a quarter of these were programmes related to toxic algae that involved Cawthron.

Figure 1.2: Funding of Output 6 compared to Total PGSF

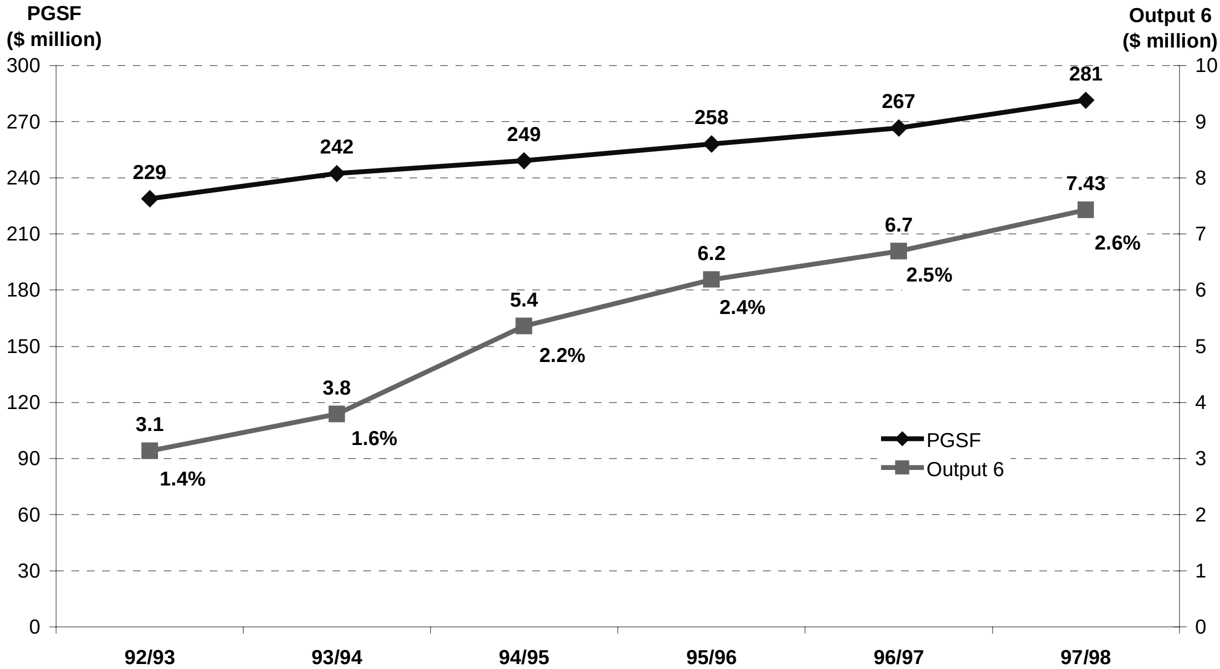
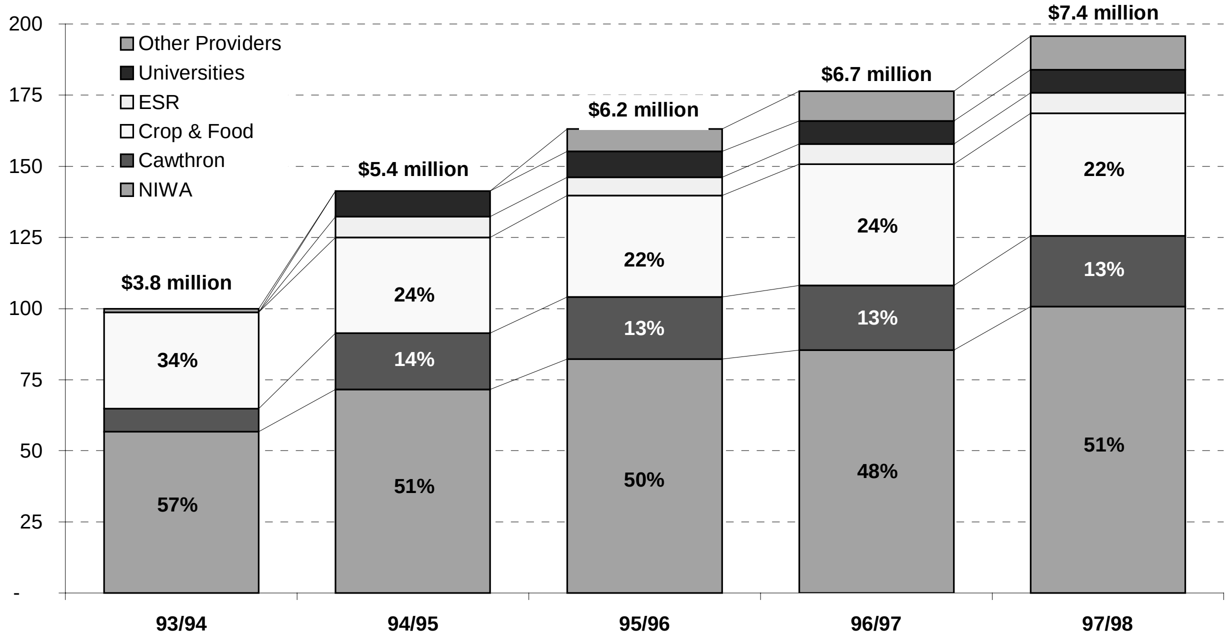


Figure 1.3: Funding by Provider (1993 = 100)



2. Research Funded by the PGSF

The stated purpose of the PGSF is to fund research that:

- will increase knowledge and understanding of physical, biological or social environments
- will develop skill bases and expertise important to New Zealand
- will generate outputs of future benefit to New Zealand
- is unlikely to be funded adequately from other sources.

In order to assess whether this purpose has been achieved, it is necessary to describe the research funded by the PGSF during the period under review.

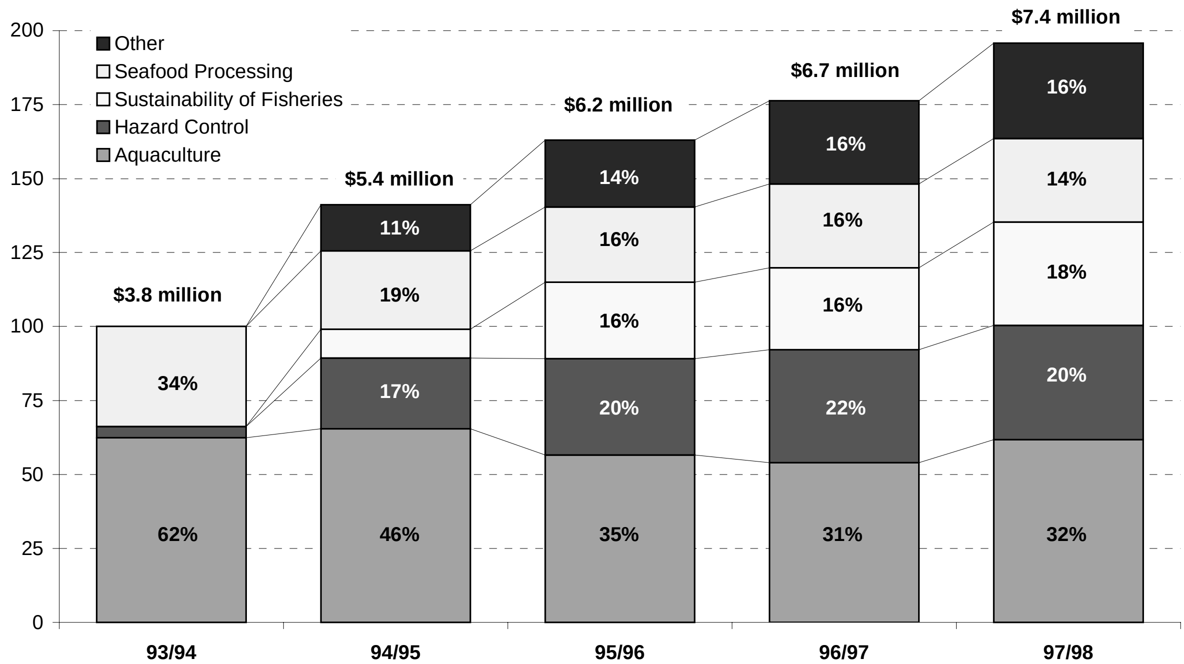
In 1993 about 62% of total funding in Output 6 was allocated to programmes which were generally to do with **the development of aquaculture**, and the remaining 34% to do with improvements in **the processing of seafood**. Funding of these categories has remained relatively constant over the period since.

The additional funding in this Output has been allocated in increasing amounts to programmes devoted to:

- **control of** hazards (toxic algae)
- the **sustainability of fisheries** (including freshwater aquaculture)
- **other topics**, including harvesting of fish, taiapure and the environmental effects of fishing.

These five categories have been used in this assessment. A summary of funding by category of research is shown in Figure 2.1. A detailed list of programmes grouped by category is presented in Appendix 3.

Figure 2.1: Funding by Category of Research (1993 = 100)



2.1 The Development of Aquaculture

In the 1993/94 bidding round, 62% of the PGSF allocated to Output 6 supported five streams of research activity relating to aquaculture. Of the total funding in Output 6:

- 44% was used to support investigations into:
  - the potential for fisheries in rivers, lakes and estuaries
  - species and stocks for freshwater aquaculture
  - the development of technologies to establish new and/or improved marine aquaculture industries (and into the enhancement of exploited and depleted coastal fisheries).

  These programmes carried out basic research into rearing of various species. Researchers have demonstrated the potential for farming paua, rock lobster, and scallops, and have provided significant information about mussels, dredge oysters and other species. Hatching facilities have been created for replicated rearing, new tanks have been designed for the rearing of rock lobsters, and the most economic feeding regime for juvenile lobster has been ascertained. There is now a greater awareness of the importance of river mouth openings at various seasons, for recruitment and escape.

  The programme may demonstrate that the culture of scallops by the mussel farming industry is feasible. It is assisting the development of spat collection techniques by mussel industry, and is developing an understanding of issues relating to the rearing of dredge oyster larvae.

- about 8% (now less) was used for research into salmon biology and population structure.

  The researchers initiated a collaborative research programme with the University of Washington School of Fisheries in 1994 to determine whether salmonids are capable of significant evolutionary divergence over decades. Families of salmon from three rivers are being reared in a common environment, to identify traits that continue to differ under these conditions.

  Results indicate that some adaptation to NZ conditions has occurred since salmon were introduced. These results have been incorporated into a major broodstock development venture within the industry, and will contribute towards better management of the fishery.

- 4% was used for research intended to improve paua farming.

  Funding for programmes specifically researching paua has increased during the period. Studies have continued into:

  - ecological interactions between paua larvae, seaweeds and micro-organisms. Differences in larval settlement and growth rates have been observed in conjunction with different strains of diatoms, and causative factors are being identified. The research will improve techniques for paua farming and wild stock enhancement
  - the physiology and functional morphology of the paua muscle, which are linked with its texture and flavour. Results indicate characteristics which may be important in site selection for paua farming, and reveal considerable scope for predicting desirable market characteristics in both wild and farmed stocks.

- another 4% was used for research into marine natural products, primarily to investigate the potential for deriving useful drugs from farmed sponges.

  These programmes have been searching for new drug and biocide leads from sponges, and examining options for the supply of both sponges and the natural chemicals themselves.

  Six chemicals derived from sponges are undergoing pre-clinical trials overseas as anti-cancer drugs. Synthesis of these drugs is either impossible or uneconomic, and sustainable harvest of the sponges cannot generate enough biomass to supply potential market demand, so supply must be generated through aquaculture.

  Three of the sponges have been successfully cultured in the sea and are being scaled up to commercial production, and new bulk production / extraction technology has been developed. A number of patents have been filed, and one compound is in the process of being licensed by a drug company. Cell culture has also been examined, and early indications are that this may be a viable option for some species.

  A feature of the programme is the environmentally aware method used for drug prospecting and development, involving a full environmental impact assessment for every target species.

- funding has been used to investigate rock lobster feed development, breeding and enhancement.

  Key elements of rock lobster reproduction and juvenile ecology are being identified, to enable controlled captive breeding of broodstock and the enhancement of wild populations. They are a precursor to large-scale experiments in collaboration with industry.

During the review period, funding was also provided for research into aquaculture of bivalves, undaria (seaweed) and flatfish. These programmes are investigating:

- the breeding biology and life cycle of mussels and oysters
- the feasibility of establishing undaria as a new commercial aquaculture crop, which is in increasing demand in parts of Asia, by developing the capability to prepare seed strings and to determine the growth treatments and methods which result in the best crops
- the breeding / growth characteristics of flatfish to assess its potential for farming.

2.2 Seafood Processing

34% of funds provided in the 1993/94 bidding round were allocated to research related to seafood processing. Funding of these programmes has continued at that level. The research includes studies to:

- improve the stability and functional properties of seafood[3]

  These programmes are investigating mechanisms for stabilising muscle proteins in order to develop integrated strategies to improve the quality and

[3] Prepared as a case study.

shelf-life of seafood products. Research has demonstrated seasonal changes in the protein level in hoki flesh and a significant improvement in shelf-life by storing harvested fish at colder temperatures than were the practice at the time.

- improve knowledge of seafood science and technology by investigating the effects of shelf-life, handling, processing and storage on the nutritive composition of seafood

  New labelling regulations in some of our overseas markets require data on the composition and shelf-life of seafood. This research will provide the technical information to support exporters and to position NZ product at the high quality end of the market.

- increase the value of our seafood resources by controlling the deterioration in post-mortem fish muscle texture[3]

  This programme has studied salmon and hoki, and created the capability to repeat the research in controlled conditions with captive fish populations of other species. The concept of 'rested harvesting' has been developed and transferred to industry, where the fish are anaesthetised prior to harvesting. The stress levels in the fish remain low, and muscle texture is maintained at a high quality.

- improve post-harvest crustacean quality

  This programme is studying the impact of the stress of capture, handling, storage and transport on live lobsters, in order to enhance their survival and quality for premium food production. The knowledge gained will allow the industry to make the process changes needed to maximise returns from the fishery by reducing mortality of the lobster.

2.3 Hazard Control

Funds increasing to 20% of the total were used for a range of programmes primarily investigating aspects of toxic and noxious algae. Research included:

- acquiring further basic knowledge of the causative organisms involved in micro-algae blooms, in order to develop and refine monitoring and toxicity testing methods[4]
- characterising the toxins and developing improved analytical methods, particularly the development of assay methods to replace the mouse bioassay
- identifying macromolecular markers for use as diagnostic probes to detect the presence of toxic phytoplankton in seawater
- developing a simple cost-effective screening procedure suitable for the certification of shellfish safety, to meet the requirements of overseas markets
- identifying microbiological hazards associated with specific seafood products and developing handling, processing, packaging and storage techniques that will eliminate or minimise these hazards.

[4] Prepared as a case study.

2.4 Sustainability of Fisheries

The aligning of the Fisheries Management Act and the Resource Management Act has led to the need for a much broader perspective to fisheries management. Very little is known about marine environments, and particularly about deep sea environments which have only recently become a useable resource - fishers are making use of resources about which very little is known. Inshore fisheries are affected by land activities and are polluted by agriculture and human life, but little is known about the effects of these factors.

Research into aspects of the sustainability of fisheries has increased over the period to about 20% of total funding. Programmes in this grouping are:

- identifying changes in the ecology of the seafloor resulting from habitat disturbance by commercial fisheries.[5]

  Studies have demonstrated trends of significantly higher densities of of large surface-dwelling animals and increased biodiversity in areas of reduced fishing pressure, and suggest that 20% of the variability in the composition of seafloor communities can be attributed to habitat disturbance by fishing.

  Researchers expect to develop rapid impact assessment techniques and investigate the ecological links between these habitats and commercially valuable species.

- investigating the impact of commercial fishing on multispecies fisheries.

  Research has identified mechanisms to minimise the impact of commercial fishing by modifying equipment and fishing strategies, and increased awareness and understanding among fishers of the dynamics and the effect of their activities

- defining the carrying capacity of coastal embayments for shellfish aquaculture.[6]

  This programme has the long-term goal of defining sustainable production levels for shellfish aquaculture in a particular embayment. The main processes affecting mussel growth and condition have been identified. Field and laboratory work is estimating parameters to be used in models of mussel growth and condition. Data collected are also providing valuable information on the variability of the factors that affect shellfish growth.

- investigating aspects of biology that are essential for sustainable management of freshwater eels.

  Recruitment mechanisms, the effect of cover availability and the influence of ration size and temperature on growth are being investigated. The programme has achieved widespread acceptance among Maori and the industry of the vulnerability of eel stocks due to the longevity of the eels.

[5] Prepared as a case study.

[6] Prepared as a case study:

2.5 Other Topics

Funding of a range of other topics started in the 994/95 bidding round and grew to 16% of total funds in the 1997/98 round. These topics include:

- the genetic enhancement of salmon

  This programme is intended to develop an effective gene transfer technique and functional fusion genes for tailor-made traits for transfer into fish stock, to enhance the productivity and quality of existing salmon stock for aquaculture.

  Researchers have demonstrated that the introduced gene has been transferred by sperm and integrated into the salmon genome. The process is now undergoing field trials. The programme is also working with regulatory bodies to develop regulations for the containment of transgenic fish.

- remote sensing of fisheries using satellite signals[7]

  This research is generating fisheries potential models to allow fishers to harvest wildstock more efficiently, by integrating historical fish catch data and satellite data records. Sea surface temperature charts are made available to fishers, and work is continuing to identify upwellings in the ocean which attract commercial species of fish.

- investigations into the defence systems of shellfish against pathogens

  One programme is investigating virus-like particles found in samples of mussels diagnosed as being sick. Another is identifying populations of oysters that are resistant to common pathogens/parasites and the mechanisms involved, with a view to enhancing wild stocks of oysters and supporting their aquaculture.

- measurement of the effects of agricultural pollutants on trout distribution, abundance and growth

  A model of the drift-feeding energetics and growth of trout has been developed. Agricultural land use increases the turbidity of rivers affected, which reduces the amount of food available to drifting trout.

- determining the impact of fishing activity on Southern Buller‘s albatrosses

  Satellite telemetry has been used to determine the feeding areas used by the birds at different stages of the breeding cycle, and this information is being compared to the location and timing of major fisheries. Fisheries-related mortality and diet fed to chicks are being examined.

- investigating the management of taiapure areas

  These programmes involve working with iwi and other community groups to develop environmental performance indicators and management regulations that are a blend of modern science and traditional stewardship. They have a strong focus on encouraging social acceptance of community involvement in the protection of marine resources.

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[7] Prepared as a case study.

2.6 Research Outputs

The leaders of all programmes covered by this review were asked by questionnaire to indicate the nature and quantity of publications produced,[8] but not all respondents provided the quantity information.

Of all respondents to the survey (refer Figure 2.2):

- 58% reported producing publications. Of those who did not report publishing, 60% involved programmes which had been running for more than a year
- 44% reported articles in peer-reviewed international journals, involving 46 articles. 17% reported publication in NZ peer-reviewed journals
- 46% reported preparation of conference papers. 33% reported that these had been published, and 39% that they were not yet published. A total of 105 papers were reported, the majority unpublished
- 22% reported preparation of technical manuals
- 33% reported other forms of publications, principally popular articles in trade journals. 98 of these were reported.

11% of respondents reported patent applications involving 15 patents, and 1 new commercial product was reported (Figure 2.3). Many respondents commented that commercial processes have been improved as a result of the research, and 19% indicated that consulting services have been developed.

Figure 2.2: Dissemination of Research Results)

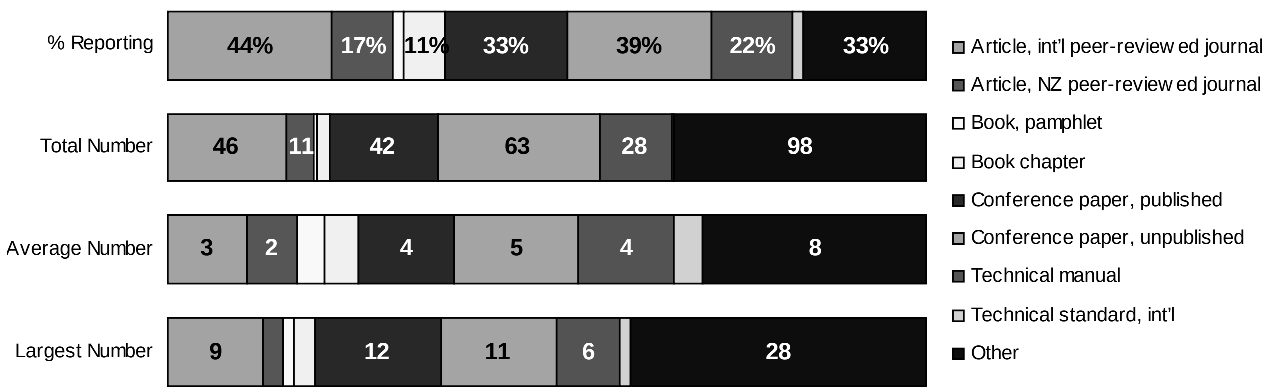
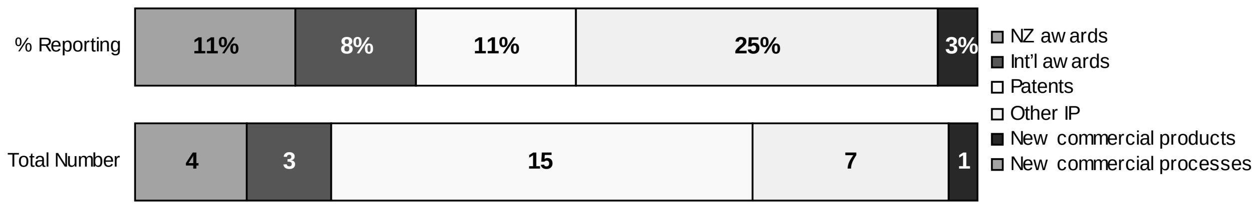


Figure 2.3: Awards and Commercialisation



[8] Programme Leader Responses

3. Outcomes of the Research

The benefits and results of PGSF supported research have been assessed through the use of questionnaires aimed at programme leaders and users thought to be affected by the research. The questionnaires were supplemented by interviews of selected representatives of both groups. Many of the topics reviewed in this section are illustrated through case studies which were prepared to describe in more detail the outcomes of specific research programmes.

The outcomes expected of research have changed over the period of the review, and scientists have had a period of 'moving goalposts'. In general, however, the outcomes expected of research fit into four categories. This review distinguishes a fifth category, the upskilling of end-users, specifically to draw attention to the fundamental role of **people** in creating intellectual capital and applying their knowledge as innovation. This review therefore uses five categories of outcomes, including:

- enhanced scientific capability - of immediate benefit to the research provider, including staff, equipment, structural or organisational capabilities
- economic impact - an increase in revenues or profitability
- upskilling of industry staff - achieved by a transfer of knowledge and ability
- environmental impact - an opportunity to preserve and protect the environment for current and future populations
- social impact - an enhancement of the general population in terms of cultural aspirations, skill development, increased employment or better health.

3.1 Enhanced Science Capability (of science providers)

Programme leaders reported improved science capability as follows:

- staff increases

  33% reported staff increases, principally recruiting from within NZ. 8% reported a reduction in staff during or after completion of the programme
- student learning

  25% reported the participation of students at MSc level, 19% at PhD level, and 14% at undergraduate level
- infrastructure or equipment

  47% reported increased capacity in terms of infrastructure or equipment. 61% of this involved the development of new aquaria and related skills, which now represents a core capability that can be applied to other species
- new or enhanced scientific methods

  69% reported developing new scientific methods. 33% acquired them through collaboration with overseas organisations, and 19% from NZ organisations. Many examples were given of the types of methods involved.

It is difficult to assess the value of the science capability developed with the assistance of the PGSF, and respondents were not asked to do so. It is clear, however, that a variety of forms of tangible and intangible assets have been created, and that these are perceived as having value in terms of providing a **platform for further scientific work** and/or for the provision of related services to end-users.

Some of these platforms are documented in the case studies. For example:

- The remote sensing programme[9] developed innovative algorithms for the interpretation of satellite data, enabled NIWA to develop the expertise and capability to access and process satellite signals, and generated valuable historical data relating to climate. The capability created can now be used for a range of climate, weather, oceanography and fisheries research

– Work done by Crop & Food to investigate the concept of rested harvesting[10] using salmon has involved the creation of a facility in Nelson based around a laboratory acquarium. This facility can now be used for almost any species of fish for testing of rested harvesting techniques and technology or to establish benchmarks and control processes. Similarly, equipment developed to measure the tensile strength of hoki muscle can now be applied to other species

– Cawthron has created the largest culture collection of toxic and noxious algae in the world, partly relying on PGSF support.[11] This collection now enables research to be carried out in NZ and overseas using samples which would otherwise not be available

– The models developed to represent the relationship between environmental variables and mussel growth in one embayment can now be applied to others, and potentially to other species of shellfish[12]

– The study of the impact of fishing on the environment, which includes work that is being done for the first time anywhere in the world, is developing rigorous rapid assessment techniques, which will be widely applicable

– All the case studies involve the creation of substantial intellectual assets

– All the case studies also involve the creation of international reputations for the scientists involved, which improves the standing of NZ science, and makes it easier to collaborate with scientists overseas.

These examples of research platforms are likely to be typical of the programmes, rather than exceptions, although only 25% of respondents report the creation of other forms of intellectual property such as new processes or scientific methods. Testing of this issue in interviews with programme leaders suggests that **the low result is more an indication of a lack of recognition of intellectual assets, rather than an indication that they are not being created**.

The evidence tends to indicate that the quality of work done in PGSF supported programmes is high. This seems to be recognised in the global science

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[9] Remote Sensing case study.

[10] Seafood Products case study.

[11] Toxic Algae case study:

[12] Sustainability of Cultured Shellfisheries case study.

community, where New Zealand scientists have been able to leverage their own expertise to benefit from the sharing of knowledge gained by offshore researchers.

Of all respondents, for example:

- 11% report winning awards in NZ, and **8% have won international awards**
- **78% report gaining additional funding** for work supported by the PGSF.

  72% of these obtained less than $100 000, but 12% reported attracting in excess of $250 000, largely from NSOF or the TBG programme. Several also had support from industry.
- **83% indicated that they are part of international networks of scientists** with whom they communicate regularly.

  53% report formal collaboration with scientists from overseas organisations, primarily involving research institutes (47%) and universities (37%). Similar collaboration within NZ is reported by 47% of respondents, involving research institutes (53%) and universities (35%), but also including industry (35%) and iwi (12%).

  Examples of formal collaboration can be seen in the case studies:

  – the remote sensing programme collaborates with several organisations in relation to its use of satellite data, and was able to secure principal investigator status against world wide competition for access to satellites operated by the Japan Space Agency NASDA

  – the seafood processing group collaborate with scientists at North Carolina State University in aspects of cryoprotection and functional properties. The two groups are acknowledged world leaders in the field. They also collaborate with scientists from Oregon State University in seasonal changes of fish proteins

  – the toxic algae expertise in Cawthron is perceived to be world leading, and widespread collaboration occurs with researchers in Japan, the US and Australia. All NZ research into toxic algae is collaborative, and is co-ordinated through the Marine Biotoxin Management Board

  – the shellfisheries sustainability programme involved multiple groups, including industry, several research institutes and overseas expertise in a carefully orchestrated collaboration

  – a researcher from the Scripps Institution participated in the programme studying the impact of fishing on the environment.

3.2 Economic Impact

Many programmes supported by the PGSF appear to have had significant economic impact. It should be noted, however, that less than half (47%) of programme leader respondents regarded industry as a potential user of their research. 25% regarded Government as the main end-user, largely for regulatory or management purposes, and 19% viewed other researchers as being end-users. A further 17% regarded the general population as end-users, for health and recreational purposes.

A number of potential categories of economic impact were identified based on responses provided by programme leaders. The extent of this impact has been assessed as far as possible within each of these categories:

- **Commercially valuable products.**

  Only one programme is reported as resulting in a product of commercial value. This has been patented and recently licensed to a commercial organisation for marketing purposes[13], but revenue figures are not available.

  The product is used in the local salmon industry to reduce stress in the fish during harvesting, which improves the quality of the final product. The new handling processes involving this product are credited with improving the quality of the product sufficiently to preserve New Zealand's position in the market during a world-wide downturn in fish sales, while competitors (Canadian) have been adversely affected.

- **Commercially valuable processes.**

  No programmes reported the development of commercially valuable processes, although many reported improvements in existing processes used by industry and Government agencies.

  Several respondents reported that their own institution was benefiting from commercialisation of their work, 19% involving the provision of consulting services and 11% involving direct sales (monitoring services, etc). Total revenue gained from these was reported at about $0.4 million p.a., but the actual figure may be higher since not all respondents provided an estimate.

- **Cost savings / efficiency gains.**

  Research into toxic algae (costing $0.9 million p.a. during this period) has:

  – reduced industry monitoring costs by at least $0.25 million p.a.

  – reduced public health costs by more than $2.25 million p.a. from 1993 levels

  – reduced levels of affected people and therefore avoided their treatment costs and loss of earnings while off work

  – enabled the industry to avoid phytosanitary trade barriers

  – enabled the industry to identify algal events as non-toxic, and therefore to continue exporting

  – enhanced the image of NZ product in its markets.

  The sea surface temperature monitoring programme[14] has cost about $0.25 million p.a. during much of this period. The outputs are now used as a matter of course by fishers to determine where to fish, and the research is credited with increasing the likelihood of finding fish, and therefore with reducing industry operating costs. Because this service has been operating for less than a year estimates of these cost savings are not yet available, but fishers themselves have been very positive about results.

  The service may be commercialised if it proves viable.

[13] AQUI-S™, developed by Crop&Food.

[14] Case study no. 1.

21% of users reported reductions in operating costs as a result of PGSF research, although 19% reported an increase in costs, generally as a result of the restrictions imposed via the Resource Management Act.

In terms of efficiency gains among government users: 36% reported revised operating policies as a result of PGSF research, and 30% reported new or improved processes.

- **Growth of industry revenues.**

  The cost of PGSF supported research enabling the development of aquaculture capability has been averaging about $2.3 million p.a., of which perhaps $0.5 million p.a. involved mussels and salmon. A further $0.5 million has been spent on other work relating to the aquaculture of these species (genetic improvement, etc).

  This suggests that research costing $1 million p.a. or less has supported the growth of a $120 million a year industry.

  23% of users reported improved competitiveness as a result of PGSF supported research.

- **Preservation of industry revenues.**

  About $1 million p.a. has been spent on research into seafood processing, affecting the hoki, dory and salmon industries primarily (with revenues of about $140 million, $35 million and $40 million respectively in 1997).

  The result has been a substantial improvement in the quality of the exported product. This improvement has enabled these industries to preserve market share during a world-wide downturn. The quality of hoki at the beginning of this period was such that it may not have been marketable at all in the current environment without the improvements gained.

  15% of users preserved markets as a result of this research, 13% reported new market opportunities, and 9% reported improved market access.

- **Future industry revenues.**

  Research in aquaculture currently involves at least eight species, and has cost less than $2 million p.a. during the period under review.

  If the rest of these species develop into industries of a similar size to the current salmon industry as a result, the collective export earnings potential could be in excess of $250 million p.a.

  One of these potential industries involves sponges, three of which have been successfully cultured in the sea and are being scaled up to commercial production. Six chemicals derived from these sponges are undergoing pre-clinical trials as anti-cancer drugs, and one is in the process of being licensed by a drug company. Several patents have been filed. These chemicals cannot currently be synthesised, but cell culture is being investigated.

  Recent research into fish proteins from by-products will enable new products to be developed, and reduce wastage from processing. The current position of this research has been compared to that of the dairy industry 30 years ago, where similar research underpinned the development of the now lucrative functional dairy protein industry.[15]

- **Trade barriers.**

  World markets for seafood are still heavily protected, although recent GATT rounds have seen improvements from NZ's perspective. Science has a significant role to play in ensuring that information is available in support of NZ exports and that it is acceptable to regulators in foreign markets.

  The PGSF has positioned scientists in a number of areas as authorities in particular aspects of phytosanitary and related trade barriers:

  – expertise built up in toxic algae has led to the NZ monitoring programme becoming accepted by our principal markets, and therefore strengthened the position of our export industry

  – because of our expertise in cryoprotection (of fish products), one of our scientists is participating in an advisory group for the International Institute of Refrigeration. He was able to resist moves to standardise temperatures used for transportation at levels too high for fish, which could have put our entire seafood export industry at risk

  – technical information provided to exporters is assisting them with the provision of nutritive content and shelf-life information as required by certain markets.

  It is probable that the impact on the environment of processes involved in providing seafood will become an issue in the market. There is already interest in demonstrating 'clean green' processes in an attempt to gain market advantage. A variety of work investigating the impact or the sustainability of fishing will assist the industry position itself favourably in its markets.

- **Regional economic impact.**

  An analysis by Berl[16] identified substantial clustering in the Nelson region around the seafood industry, with a range of suppliers of goods and services becoming established with strong links to the industry. Berl indicates that the seafood cluster in Nelson has generated half of all new jobs created between 1994 and 1997.

  An investigation by Lincoln University[17] on the impact of the wine industry on regional economies concluded that each $1 demand for wine and grapes generates nearly $4 of related economic activity.

  It is probable that a similar study on the impact of the seafood industry on regional economies would have similar results. Research that results in increased economic activity in the seafood industry can therefore be expected to create related economic activity in the local region. Research funding of less than $4 million p.a. (since 1992) has been used to develop aquaculture industries that now earn about $120 million p.a., and by their

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[15] Case study: Optimising the Value of Seafood Products.

[16] *The Driver Clusters of the Nelson Regional Economy*, BERL, May 1998

[17] *An Economic Analysis of the Wine Industry in Marlborough*, Agribusiness and Economics Research Unit, Lincoln University, March 1998

nature tend to be situated in remote areas. This research could therefore have resulted in direct and related economic activity of up to about $600 million (using Lincoln's 4:1 multiplier).

3.3 Upskilling of End-Users

Two significant and vital outcomes of PGSF supported science have been:

- an indication of what can be achieved – **the potential quality** achievable
- the raising of general awareness and understanding among end-users.

While not all parts of the industry have reached similar levels of sophistication in terms of self-organisation and the ability to absorb knowledge, considerable improvements have been made during this decade, and the PGSF has had a significant role in supporting this. The industry has developed a range of 'stakeholder' organisations representing the interests of those involved in particular species, and these new organisations have taken a leading role in fostering relationships with science providers.

The Mussel Industry Council, for example, developed its own research strategy by involving all its farmer members, and then worked with science providers to obtain their research needs. The Council has a Research committee that is able to communicate with the scientists using common language and understanding, and is able to ensure that research results are successfully disseminated to Council members.

Leading companies in the industry and the larger local bodies have created their own research and development units, which similarly work closely with scientists. These companies have now begun to purchase research directly from science providers, which is, however, confidential to themselves.

The Seafood Industry Council established an industry training organisation, which together with the polytechnic-based Schools of Fishing, serves as a principal vehicle for upskilling and educating employees of the smaller companies in the industry and to a certain extent the public.

The other significant means of knowledge transfer through the industry is via suppliers of goods and service to the industry, who apply what they learn from a job for the larger companies to work done later for smaller companies.

The PGSF has assisted these processes in two ways:

- **Setting goals**

  Fishers, like many commercial organisations, have not generally been in a position to review the quality of their product and processes except on an incremental basis. Researchers have been able to investigate harvesting or processing methods from first principles, and to determine benchmarks for the industry of what is possible.

  The dramatic improvement in salmon and hoki during this decade is largely the result of scientists gaining an understanding of the physiology of the fish, establishing control over capture, and establishing the quality potential for the fish. This potential, provided to industry as a benchmark, persuaded fishers that it was worth revising their processes and investing in technology to improve their product.

- **Education**

  Many of the scientists involved in PGSF supported programmes contribute to an increasing level of awareness and understanding among employees of the seafood industry. Programmes funded from public sources generally involve various forms of knowledge transfer.

  These issues were reviewed by survey of programme leaders:

  – 64% of programme leaders report having involved end-users in programme development, largely for objective setting, although 22% involved extensive consultation
  – 35% report collaboration with industry, and 17% report industry involvement through provision of samples or in-kind support (use of vessels, facilities, etc).
  – The sustainability of cultured shellfisheries programme[18] provides a good example of collaboration and knowledge transfer. It has developed information that will assist effective management of shellfisheries by indicating optimum loading on the embayment
  – 39% report disseminating results to industry, through popular articles in trade journals, seminars, workshops and 'road-shows'. Users also report relying on informal discussions with scientists (47%) and joint working groups (36%)
  – researchers have run several training programmes in processing premises to improve the technical skills of staff
  – scientists also work with educational institutions, preparing course curricula and unit standards, providing course material, and lecturing.

3.4 Environmental Impact

The funding of research into the environmental impact of fishing activity has been generally seen as a quota management issue, and has been primarily the responsibility of MFish, using levy funds. Programmes supported by the PGSF are therefore not expected to have a significant impact in this area.

The greatest impact of PGSF research on the environment appears to have been in terms of **management strategies and regulations**:

- 28% of programme leaders reported changes in regulations as an outcome of their work, 19% reported development of indicators, and 11% reported 'green' standards developed.

  The majority of the examples of impact given by programme leaders[19] related to resource management or knowledge of the environment.

- 21% of users reported that the research was the basis for new regulations, and 15% that existing regulations were revised

[18] Case study: Sustainability of Cultured Shellfisheries.

[19] Programme Leaders Responses.

- 25% of users reported a beneficial outcome in terms of preservation of species, and 21% reported improvements in the quality of marine ecosystems.

The other forms of impact reported included:

- **ethics**

  Research into phytoplankton monitoring is resulting in a reduction in the use of mouse bioassays, which are increasingly an ethical problem.

  The rested harvesting techniques developed provide for humane handling and slaughter of aquatic organisms.

- **waste management**

  Research into processing efficiency is identifying ways to reduce wastage. Related research into labile proteins is identifying new opportunities to develop new products from waste or processing by-products.

- **'green' techniques**

  There are several examples of 'green' techniques and technology, including:

  – drug bio-prospecting and development
  – the development of sustainable production techniques for target sponges
  – the farming of paua and rock lobster
  – the development of rigorous and rapid assessment techniques to determine the impact of fishing on the environment, which may assist the development of 'clean green' certification
  – the need for fishers to modify their equipment and fishing strategies to minimise their impact on the environment.

Users were asked their views on the role of the PGSF in the achievement of the environmental impacts they described:

– 23% of industry regarded the PGSF as an essential component, and another 15% regarded the PGSF as 'useful'

– 43% of local and central government users, on the other hand, regarded the PGSF as essential. These users tended to the environmental impact of the research considerably higher than industry users.

3.5 Social Impact

In general industry users saw social benefits in terms of increased employment opportunities, while local and central government users took a rather more long term view. The two groups clearly reflect differing priorities, where latter group is more concerned with social goals than the former.

Programme leaders reported a social impact of their research in several categories:

- **Education**

  39% reported increasing general understanding and awareness among the population.

Fishers in particular are reported to have become more aware of the value of scientific investigation, and to have gained better insight into the dynamics of their fishing. This is expected to help encourage implementation of the Fisheries Act.

A number of students have achieved MSc or PhD degrees while being involved with PGSF programmes.

25% of users also reported that the research has had impact in terms of education and skill development.

- **Maori**

  A substantial part of the industry now has Maori ownership and employs Maori. Any research that improves industry performance will therefore benefit Maori groups.

  25% of programme leaders reported strong involvement with community groups, particularly iwi:

  – iwi have been provided with information and advice with regard to biotoxins
  – the new aquaculture opportunities involving drug development is ideally suited to small scale regional (iwi) development, and this has been initiated
  – there has been widespread acceptance among the Maori community and the eel industry of the vulnerability of eel stocks
  – researchers are working with iwi in blending science with customary practice for husbandry of kai moana, and are involved in training of the Iwi Conservation Corps.

  11% of users reported benefits to Maori community and development.

- **Employment**

  19% reported that employment in certain industries and areas (such as the hoki fishery based on the West Coast, which has high levels of unemployment) would have decreased but for the successful outcome of their research.

  Several cases were reported where employment has increased as a result of new aquafarming ventures or of extensions to fishing seasons.

  Current research into aquafarming of new species, if successful, will result in the creation of new jobs and further develop employment among supply organisations (refer to the section on the impact on regional economies on page 20).

- **Public health**

  11% of programme leaders and 15% of users reported improvements in public health as a result of research into toxic algae, the development of monitoring programmes, and the development of new industrial biocides.

19% of users regarded the PGSF as an essential component in the achievement of these social impacts, and another 8% regarded the PGSF as ‘useful’. Local and central government users again rated PGSF research higher than industry users.

4. Appropriateness of PGSF Funded Research

In order to assess the appropriateness of research supported by the PGSF, this review summarises the objectives of the various organisations involved in funding or benefiting from the research, and draws on information gained by survey, interview or other means to arrive at a conclusion.

It then summarises issues identified by respondents as either currently facing them or expected to arise in the near future, and compares these to the issues being addressed by current research programmes.

4.1 Achievement of PGSF Objectives

The PGSF is intended to fund research that will:

- **increase knowledge and understanding of physical, biological or social environments**

  Section 2 of this review detailed the research being done in this Output and provides a summary of the knowledge and understanding being created of our marine animals and their environment. Significant advances in public good knowledge are being obtained through support of the PGSF that would otherwise not be available.

- **develop skill bases and expertise important to New Zealand**

  Section 3.1 demonstrates that our science capability is being enhanced through PGSF supported research in terms of staffing, expertise and world-wide recognition of scientists, and in terms of the intellectual capital being created.

  A significant aspect of this science capability is the technical platform[20] created through many of the programmes, where, in addition to delivering the outcomes expected of the programme, a core capability has been created which can now be used in support of further science or industry activity.

- **generate economic outputs of future benefit to New Zealand**

  The economic benefits of research programmes (increasing in cost from $3.8 million in 1992/93 to $7.4 million in 1997/98) include:

  – **increased revenues** for science providers of at least $0.4 million p.a., which can be expected to increase considerably with future commercialisation following current programmes

  – quantifiable **cost reductions** of at least $2.5 million p.a. through improved testing regimes for toxic algae

  – **increasing revenues** from aquaculture, currently worth $120 million p.a.

  – **preservation of position in markets** worth $215 million p.a. to NZ, as a result of product quality enhancement, during a world-wide downturn

[20] *How Science Drives the Economy*, Dr Peter Winsley, Ag Science Vol 11 No 1, page 37

- an increasingly strong **image** in seafood markets, associated with quality and environmentally safe product, which benefits other New Zealand products
- considerable potential for the development of **new aquaculture-based industries**, estimated to be worth in excess of $250 million p.a. if each grows to a size similar to the current salmon industry
- the development of considerable **related economic activity** in regions of New Zealand which would otherwise be depressed
- a world-wide reputation in specific disciplines which has provided NZ with a strong science backing for negotiations with international standards setting bodies and with market regulators using non-tariff barriers, thereby preserving or enhancing NZ's **ability to compete**

  This reputation has also enabled New Zealand researchers **to benefit from and leverage offshore science activity** through collaboration.
- a greater **awareness of the market potential** of seafood products, and of the value of science in realising that potential.

• **generate environmental outputs of benefit to New Zealand**

Environmental benefit has been obtained, mainly by **enabling better management of fisheries** through:

- better information and performance indicators, benefiting both regulators and users
- a better understanding of the inter-dependencies within our marine ecologies
- a better understanding of the effect of fishing on the carrying capacity of the habitat.

Other benefits include:

- a better **ethical position** with regard to the use of animals for testing, and in relation to the humane handling and slaughter of aquatic organisms
- a reduction in **levels of waste** disposed of, through the development of methods of developing value from fish waste, and of better processing techniques
- the development of **'green' techniques and technology**.

• **generate social outputs of future benefit to New Zealand**

Several forms of social benefit have been obtained, including:

- **changed behaviours** as a result of a greater understanding and awareness in the industry and the population of issues affecting the marine environment
- an **upskilling** of the fisheries industry through outcomes generated by research, education provided by researchers, and knowledge transfer to industry through a variety of means
- greater **involvement of Maori groups** (about 40% of the industry is owned by Maori)

- increased **stability of employment**, and reduced social dislocation
- **opportunities for increased employment**, particularly in areas which currently have high unemployment
- **improved public health** as a result of research into toxins.

4.2 Sources of Funding for Research

The PGSF is expected to be used for research that is unlikely to be funded adequately from other sources.

The various sources of funding for research in Output 6 are listed in section 1.5 (page 4), and include the Ministry of Fisheries (Vote: Fish and the industry levy), other public funds, and organisations with a strong interest in the marine environment (research institutes, industry, recreational groups, community groups).

Other sources of public funding have specific purposes and are generally used to complement the PGSF. It is common, for example, to find TBG funding used by a private company to contract a science provider to carry out applied research related to existing PGSF programmes - considerable leverage is therefore obtained from PGSF research.[21]

Similarly, CRIs use NSOF to supplement PGSF programmes or to support research before PGSF support can be obtained (as occurred early in both the toxic algae and sustainability of shellfisheries programmes).[22]

The case studies demonstrate that the PGSF has been used for basic research that was to the public good, research that individual companies had no interest in funding, or research that was considered inappropriate for individual companies to fund. For example:

- The work on toxic algae has delivered benefits in terms of public health. The entire seafood industry also benefits, but so do recreational and customary rights fishers, as well as consumers of seafood products.
- The sustainability of shellfisheries programme involved a study of processes in a complete embayment, in which there were several marine farms. Individual farms could not have funded the programme. The research carried out has enabled the science providers to develop knowledge and expertise that has much wider application that those individual marine farms.
- Much of the seafood processing research was deliberately done with PGSF support rather than as a contract to a fishing company, to avoid the outputs being ‘captured’ by individual companies and to ensure that the industry at large was able to benefit.

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[21] Refer Figure 1.1.

[22] Refer to the Toxic Algae and Sustainability of Shellfisheries case studies.

There were a number of reasons why individual organisations had no interest in funding research that was, in the event, supported by the PGSF:

- the research was promoted by scientists who could see the opportunity but could not assure a successful outcome at the beginning of the programme. During the early part of the period under review, there was considerable distrust of scientists by industry, who felt that they were being asked to support research that was only intended to further scientific careers
- some research, particularly in relation to the impact of fishing on the environment, has been seen as potentially restricting industry, which was understandably reluctant to support it
- private companies perceived the probable return on investment as too low, or the risk of failure as too high
- the research would benefit several companies, including those that did not provide financial support. If these other companies were competitors, then the proposition would clearly not be attractive
- the research involved data collection or participation by a group of companies (such as the research into the carrying capacity of an embayment including several mussel farms)
- individual organisations could not see the relevance of the research to themselves
- organisations did not have the resources required to participate. For example, recreational fishing is not subject to a levy, and groups representing recreational fishers have very limited funding available for research.

The emergence of sector representative groups (such as the Mussel Industry Council) provided an alternative route for knowledge and technology transfer. The groups were able to form their own research committees, obtain the support of individual companies, and relate or contract with the science providers on behalf of the companies.

While it may appear in hindsight that the benefits obtained from particular streams of research were sufficient to justify funding of the research, it was usually not clear at initiation. Two examples illustrate this difficulty:

- Researchers in seafood processing programmes believed that substantial quality improvement was possible in salmon and hoki and proposed to investigate that, but the industry thought they were already doing as well as was possible, and were not interested in supporting the programme
- Studies of sustainability and the impact of fishing on the environment may in the medium term enable the industry to differentiate in its markets on the basis of a certified (acceptable) impact on the environment.

In general it would appear that the industry increased its sophistication and its ability to absorb knowledge during the period under review. There is a much greater willingness to invest in research activity at this end of the period than was evident at the beginning of it. The initial distrust of scientists is considerably diminished, although the other factors noted above may still apply.

4.3 Government's strategic goals

Government's strategic goals for the PGSF were first presented in the 1992 Science Priority Statement and were expanded in the 1994 Strategic Statement. The Foundation's research strategies for Output 6 took account of these overarching goals. The key elements of these strategies are:

- Science Goals
  - Develop and maintain science capabilities, including skills and knowledge
  - Maintain and strengthen international scientific and technological networking and collaboration
- Environmental goals
  - Enhance protection of the environment through an improved understanding of biodiversity, biological and physical systems and the impacts of human activities
  - Ensure sustainable resource management (protection and use) through an adequate knowledge of natural systems, including ecosystems and their sustainable limits
  - Increase understanding of natural physical and biological hazards
  - Improve knowledge of technologies for sustainable resource use
- Economic goals
  - Maximise the contribution of research, science and technology to enhancing the quality of life in NZ
  - Enhance international competitiveness through innovation
  - Ensure that service, production, and processing industries are economically, environmentally and socially sustainable
  - Achieve a balance between research on new products and services compared with existing products and services
  - Increase our knowledge and understanding of NZ's competitive advantages and disadvantages
- Social goals
  - Improve our understanding of key issues affecting the acquisition of skills and knowledge necessary for the full engagement of individuals in society
  - Improve our knowledge of the social and cultural dimensions and trends of a competitive economy
  - Support Maori development aspirations
  - Integrate social research into research relevant to changes in the economy, resource use, the environment, human health and wellbeing.

In summary: "*the government invests in underpinning knowledge and technologies - this platform is leveraged by users to generate social, environmental and economic benefits*" (MoRST 1998).

The Foundation assesses all applications for PGSF support according to these and other goals, and approves those which best satisfy the required outcomes and can be supported by funds to the relevant Output for the financial years involved. It was therefore to be expected that the outcomes of research supported by the PGSF would satisfy these goals, as demonstrated in the previous section.

4.4 End-User Strategic Research Requirements

The seafood industry sponsored the development of a strategic research plan in 1997,[23] in support of the industry's desired transformation from being a commodity producer to becoming a market supplier.

The strategy document refers to four groups of critical issues:

- Consumer requirements

  Consumers are increasingly demanding food products that are considered to be safe (after toxin issues in NZ, the BSE scare in the UK, egg safety issues in the US, etc). They are also demanding products that are thought to contribute to good health, increasingly prefer fresh product, and require consistently high quality. Ethical considerations are emerging, in relation to animal health and welfare.

- Market access

  While import tariffs and trade restrictions are generally reducing, non-tariff barriers are expected to increase, providing access to markets:

  – if particular product standards are met
  – if the product is demonstrably free of specified diseases or pests
  – if particular information disclosure requirements are met
  – if its production has had an acceptable impact on the environment.

- Production

  The industry's ability to produce seafood on a sustainable basis is constrained by its dependence on variable wild fish stocks, water quality, supply of juveniles for aquaculture, and its exposure to the effects of disease and toxins. The industry is faced with overseas competitors that are subsidised by their governments, and production efficiency must be improved continuously for it to survive.

- Co-ordination of seafood research strategies

  Until the preparation of the draft research strategy plan in July 1997, the needs of the industry for research had not been agreed and documented. The industry was therefore not able to influence research funding effectively or to ensure co-operation with and between science providers.

  This has resulted, in the view of the industry, with low levels of Government funding, mis-directed research, and a knowledge deficit when compared to other (land-based) industries. It has also resulted in ineffective methods of knowledge transfer within the industry.

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[23] *Strategic Research Plan (draft)*, prepared by Clement & Assoc for SeaFIC, July 1997

In developing an industry strategy to deal with these critical issues, five research goals were determined. These were:

- To invest in market research, innovative product development, improved product availability and consistently high product quality

  This requires differentiation and branding of product, improved planning of supply, extended shelf-life, and continued research into the fundamental properties of seafood to underpin the development of new products and improved quality.

- To improve the quality and safety of seafood exports so as to overcome non-tariff trade barriers

  This requires cost-effective testing methodologies, better understanding of the sources of variance from standard, and the credibility to participate in international fora dealing with food standards. The industry must have a far better understanding of the physiology and habitat of its product, and be able to provide information to customers on its product as required.

- To understand wildstock and aquaculture fisheries systems well enough to allow sustainable supply of fisheries products

  It is essential that the industry can demonstrate to customers that it has an acceptable impact on the environment in all stages of capture, harvesting and processing. It must protect its stock from disease or the introduction of exotic species, and improve control of the life cycle of farmed stocks.

- To continually improve the cost-effectiveness of fisheries production

  Economic factors must be integrated into all aspects of fisheries management and production. Farmed species must be modified to enhance desired traits, and new fisheries must be found and developed. New products must be developed from fish waste. Production methods must be made more efficient.

- To improve industry co-ordination of seafood research strategies

  Better targeting of research is needed, and the level of funding of fisheries research must be increased. Both government and industry need to recognise the value created by research in fisheries, and the industry must ensure best use of available funds by determining priorities.

4.5 Other Research Plans

While many of the other (non-industry) end-users of research in Output 16 may have articulated their needs on an individual basis, there are no strategic research plans generated by groups representing recreational users, iwi, or the local bodies.

There are a number of research strategies with relevance to fisheries prepared by Government agencies. These include general strategy documents such as RS&T: 2010 (prepared by the Ministry of Research, Science and Technology), and more fisheries-specific documents prepared by the Foundation for Research, Science and Technology and the Ministry of Fisheries.[24]

Some industry sectors have prepared their own detailed research strategies, including the Mussel, Oyster and Rock Lobster industries.

The Mussel Industry Council in particular has involved its members in its determination of research needs, and appears to have very successfully used the result to influence research direction among science providers.

4.6 Issues Currently facing End-Users

All survey respondents were asked about the technology or knowledge-related issues currently facing them. The responses[25] have been grouped into categories, most of which can be related to the goals described in the seafood industry's strategic research plan.

The categories include:

- processing

  30% of respondents described processing issues, including yield maximisation, cost reduction, quality improvement, storage

- stock assessment and management

  23% described stock issues, including the aging of fish, stock inventory, fisheries management

- aquaculture

  19% referred to issues relating to the development and improvement of aquaculture

- strategy [development]

  15% referred to strategic issues, such as resource allocation, investment strategy, distribution of information

- food safety

  15% described safety issues, including ballast water, algae movement, HACCP, contaminants

- catch efficiency

  13% referred to issues relating to net designs, fish finding, seasonal effects

- other

  A number of other issues were noted, including methods of determining sustainability, determination of the impact on the environment, the need for population assessments, the impact of tourism, injuries, information technology.

[25] User Responses.

Government and other non-profit organisations responded with issues more related to their regulatory role,[26] which have also been grouped into categories:

- ecosystems interactions

  29% of these respondents referred to the design and assessment of ecological networks

- impact on the environment

  29% also referred to issues relating to the introduction of new species

- stock assessment

  21% described stock assessment issues in freshwater, the tuna fishery and the Ross Sea

- algal blooms

  21% referred to the need for improvement in the testing, identification, and prediction of algal blooms

- other

  Other issues were referred to, such as the impact of environmental factors on marine farming, nutrient limitations, by-catch issues, and the control of transgenic organisms.

4.7 Future Technology or Knowledge-Related Issues

Users were asked a supplementary question on other issues which they anticipated having to face within the next five years. This reinforced many of the issues already noted, but added a number, including:

- determining the nutritional content of fish and oils
- use of new information and communications technology
- access to offshore markets (technical barriers) and other aspects of food safety, including toxicological aspects such as Mercury content
- genetic enhancement
- increasing customer expectations in terms of freshness, 'green' aspects, live product, adding value to marine oils, etc.

Government organisations (non-profit respondents) added:

- assessment of risk of environmental impact
- biomass limitations for marine farming
- beneficial uses for the shell from shellfish processing
- proving 'clean green' in the fisheries sector.

[26] Non-Profit Responses.

4.8 The Appropriateness of PGSF Supported Research

The seafood industry regards the total level of PGSF funding supporting research in Output 6 as disproportionately low compared to the funding of other industries. This comparison is illustrated in Figure 4.1, which is based on export earnings only.

Figure 4.1: Levels of PGSF by Output vs Export Earnings

Industry	Exports ($ million)	1996/97 PGSF ($ million)	PGSF / Export
Dairy, Meat and Wool	6 768	69.5	1.0%
Forestry	1 531	22.5	1.5%
Seafood	1 147	6.7	0.6%
Fruits	818	50.7	6.2%
Other	10 284	117.6	1.1%
Total	**20 549**	**266.9**	**1.3%**

The issues identified by the survey respondents match reasonably well with the research goals identified by the seafood industry (as described in section 0).

In order to assess the appropriateness of PGSF research, these issues were grouped with the industry research goals, and the list related the categories of PGSF programmes (Figure 4.2).

Figure 4.2: Relationship of PGSF Funding to Research Need

Research Need	PGSF Allocation 1997/98			
	PGSF Category	Species Involved	Funding (% of total)	
Product Development, Availability and Quality				
New products	Development of Aquaculture	Several	31%	(part)
Genetic enhancement	Genetic Improvement	Salmon	2%	
Seasonality	Seafood Processing	Hoki, salmon	14%	(part)
Customer expectations (freshness)	Seafood Processing	Hoki, salmon, rock lobster	14%	(part)
Food Safety and Market Access				
Biotoxins	Hazard Control		12%	
Other toxins (Hg, Cd)				
Contaminants	Hazard Control		7%	
Certification ('clean green')				
Nutritional content				
Product information	Seafood Processing	Hoki, salmon, rock lobster	14%	(part)
Environmentally Sustainable Production				
Stock assessment and management	N/A	(MFish)		
Aquaculture	Development of Aquaculture	Several	31%	(part)
Impact on ecosystems	Sustainability of Fisheries		18%	
	Other (Buller's Albatross)		3%	
Protection from disease	Resistance to Disease	Shellfish	3%	
Risk assessment				
By-catch issues	Seafood Processing	Hoki	14%	(part)
Cost-Effective Production				
Yield maximisation	Seafood Processing	Hoki, dory	14%	(part)
Processing cost reduction	Seafood Processing	Hoki, salmon	14%	(part)
Storage and transport	Seafood Processing	Hoki, salmon, rock lobster	14%	(part)
Catch efficiency	Seafood Harvesting	Wild stock	3%	
Investment strategy	N/A			
Effective Management of Fisheries				
Taiapure	Taiapure Fisheries		2%	

At least two areas of research need identified by SeaFIC or survey respondents would not normally be considered for support by the PGSF:

- The Ministry of Fisheries (MFish) is primarily responsible for research relating to stock assessment and management issues, and has a budget of about $15 million which is used primarily for this. Part of the MFish budget is used for research relating to recreational usage of the marine environment
- Investment strategies are business issues, which are currently supported by Technology New Zealand (not the PGSF).

4.9 Areas of Need

It appears that there is PGSF support for programmes in most areas of need, although the scope of the work involved may not match the scope desired, either by the type of research or because of the limited range of species involved. There do seem to be areas of need, however, where there is currently very little PGSF supported research. These include:

- The incidence of toxins other than biotoxins
- The need for 'clean green' certification (some preparatory work is being done)
- The need for product specific information for use in gaining market access or preventing loss of access due to non-tariff trade barriers
- The nutritional content of seafood products (although some work on this is being done by Crop&Food's Seafood Group)
- Assessment of risk in relation to the environment and fishing or farming
- Utilisation of fish waste (current work research appears to be limited to the labile protein research being carried out by the Seafood Group).

4.10 Unsuccessful Applicants

A number of unsuccessful applicants for support from PGSF were interviewed to find out what happened to the application after the decision, and to determine whether there were lessons to be learned from the outcome.

There were two main issues involved in these cases:

- Applications were considered not appropriate for PGSF support. Some were later submitted to other funding sources, and some were simply withdrawn.
- Applications were not highly rated by the Foundation. In most of these relevance was reconsidered and more comprehensive applications made in following bidding rounds. In a few cases the organisation concerned redirected its activities following the failure of its application.

There appeared to be no particular issue in relation to the appropriateness of the PGSF or the process used to allocate funds. It is worth noting, however, that:

- small organisations can incur a high cost in making applications
- discontinuities in funding can have a serious impact on an organisation even for relatively small projects
- there is a perception that the PGSF advisory committees are inclined to support big organisations and traditional science providers.

5. Conclusions

5.1 Appropriateness of Research

The previous section suggests that Government objectives for the use of the PGSF have been met in this Output during the period of this review.

The seafood industry considers that the total level of PGSF funding of research in Output 6 has been inappropriately low (at 0.6% of export revenues) when compared to funding of land-based primary industries (Figure 4.1 on page 34). Funding has, however, increased over the period at an average rate of 18% p.a.

The need for research was tabulated in Figure 4.2 on page 34, based on a review of government objectives, the seafood research strategy prepared for SeaFIC and the issues raised by respondents to the questionnaires. This need was compared to the PGSF programmes actually undertaken during the period under review.

The rough comparison suggests that the set of programmes funded by the PGSF are broadly consistent with the outcomes currently being looked for by end-users, although the relative funding of each category may be considered by some to be inappropriate.

Although the topics required are generally covered by current programmes, the scope of the research in terms of species appears to be quite narrow. This illustrates the importance of the PGSF in developing science capability, often on one or two species, which may then be applied at much lower cost and with greater speed to a variety of other species. In general, this application of capability and findings to other species is only just beginning.

There have, however, been areas of research need identified by end-users in this review which appear to be a minor part of current research programmes, if they are being studied at all. These include the incidence of toxins other than biotoxins, the need for certification of 'clean green', and the need for information on the nutritional and nutriceutical content of seafood products.

5.2 The Process of Innovation

It has been suggested in this review that the seafood sector has developed in sophistication and its ability to absorb and apply knowledge during the period under review (refer section 1.3 on page 2). To a considerable extent this has been a result of science activity supported by the PGSF, where relevance has been considered by the Foundation in considering applications, and where the scientists have made the effort to transfer knowledge to end-users.

The process of assisting the sector help itself is an important outcome of the use of public funds, and is arguably the most important outcome. The process has required:

- initial research to gain an understanding of issues in the sector
- the development of a view of the potential for performance, quality of product or range of products

- communication of this view to organisations in the sector, to persuade them that there is potential for improvement and that it is worth striving for it
- developing research programmes in collaboration with end-users, to ensure that the outputs are taken up by them
- assisting end-user organisations build up their own capability to understand, absorb and apply the outputs of the research
- persuading end-user organisations that it is worth their while to invest in research.

Many examples of where this process has occurred are documented in the case studies (Appendix 4).

The seafood industry presently consists of sectors at varying degrees of sophistication. The Mussel Industry Council and the larger organisations (including both fishing companies and regional councils) are investing effectively in their own research, often using TBG funding to support applied research spinning off from PGSF programmes where the organisation concerned can see benefit to its own stakeholders. This evidence of leverage being gained from PGSF programmes is a good indication of the value of the basic research being undertaken.

For the next tier of organisations to participate, the process of becoming involved needs to be made simpler. Many interviewees commented about the difficulty of applying for TBG funds, let alone applying directly for PGSF support. To a certain extent this difficulty is being taken up by representative groups, who have learned how to make successful applications, and are coaching their members or peers in the process. The application process could, however, be made easier for new entrants.

Many interviewees also commented on the difficulty they had in establishing what research was being done, by whom, and how the research might apply to themselves. The view of scientists on this issue is that the end-users should make a reasonable effort to find out for themselves. This gap in communication is easily understood, if end-users and scientists are both focussing on their primary tasks.

The gap is relatively easily bridged, however, and there would be considerable advantage all round if it were. NIWA , for example, goes some way to reducing the gap with their Aniwaniwa magazine, which includes popular articles on research of interest and provides contact details for the scientists involved. Bridging the gap effectively could involve:

- providing a single point of access for users to the names and contact details of scientists and organisations, searchable by topic or expertise area, with examples and expected outcomes provided in layman's terms. The Internet may prove an effective medium for this, since it is now increasingly rare to find an organisation without some form of access
- circulation in popular article form of summaries of topic areas, progress and expected outcome of research programmes. This is now happening to a limited extent with the *Seafood New Zealand* magazine.

The innovation process appears to be becoming more effective in this industry. An effective structure is in place, the signs are that the industry is improving itself. There is therefore every reason to expect continued improvement during the next few years.

5.3 Intellectual Capital

During preparation of the case studies, it became apparent that the interviewees were generally not used to thinking of their programmes in terms of the intellectual assets being created. In each case study, significant assets appear to have been created, which either provided a capability for the science provider to carry out related research, or had commercial value.

Further discussion with senior managers of the research institutes indicated that they were aware of the value of assets created by the programmes in terms of their own enhanced capability to carry out research. It appears, however, that assets such as databases created to a large extent through the use of the PGSF are often not readily accessible to researchers from other organisations, and in fact the latter were sometimes unaware that the knowledge or data even existed. No cases have been reported, however, where industry had requested information and been refused access by the science provider.

Current policy allows science providers to retain the rights to assets created by their own researchers using public funds, but requires that the asset (once developed as contracted) must be released on request for a 'fair price'. This price should take into account the value added in intellectual property during the programmes concerned.

There is a view in the industry that knowledge developed with their funds (in the case of the levy) or with their participation should not be sold or used in the delivery of services to their overseas competitors. A view expressed by scientists is that where industry displays no real interest in taking up particular outputs, then the science provider should be free to realise the value of their work in other ways. This issue has arisen with the fish anaesthetic AQUI-S™, and potentially applies to other research outputs.

Both parties appear to have learned from experience, and research contracted directly by end-users is often subject to contracts that explicitly deal with ownership of intellectual property created during the contract.

There have been few examples of commercially valuable assets being produced. Some of these are, however, described in the case studies: [27]

- a process has been developed to provide sea surface temperature data to fishers. This programme is still proceeding, and NIWA may offer the service on a commercial basis if it proves viable
- Cawthron have developed a viable commercial monitoring service for the aquaculture industry, checking for toxic algae
- Crop&Food have developed a product to anaesthetise fish (AQUI-S™), which has been licensed to a private company for commercial development. This company will earn revenues by promoting its products overseas, benefiting its shareholders and the wider community, but will also benefit competitors of NZ industry

[27] Refer to Case Studies.

- The sustainability of shellfisheries programme has developed a knowledge base that will be of significant benefit to NZ farmers. The science providers may regard this knowledge as an exportable commodity, and gain revenues from overseas farmers, while reducing the competitive advantage gained by NZ industry.

While these examples may prove exemplary in terms of effective realisation of the value of assets created during research programmes, there are others where potentially valuable assets may be at risk when current funding runs out. Funding of Cawthron's culture collection has come from the PGSF, but this funding may not be renewed. Cawthron do not benefit from NSOF which is available to the CRIs, and will presumably have to find other means to fund the maintenance of its globally valuable asset, and to retain key staff.

The commercialisation of new products and services is a difficult area in NZ. The country as a whole suffers from a lack of expertise in assessing the viability of new ventures. It also suffers from a lack of any significant funding for new ventures other than the debt market, which is usually not a viable option. Funds considerably larger than those available from the TBG programme are required.

If effective gains to the economy are expected from research programmes, some thought should be given to these problems.

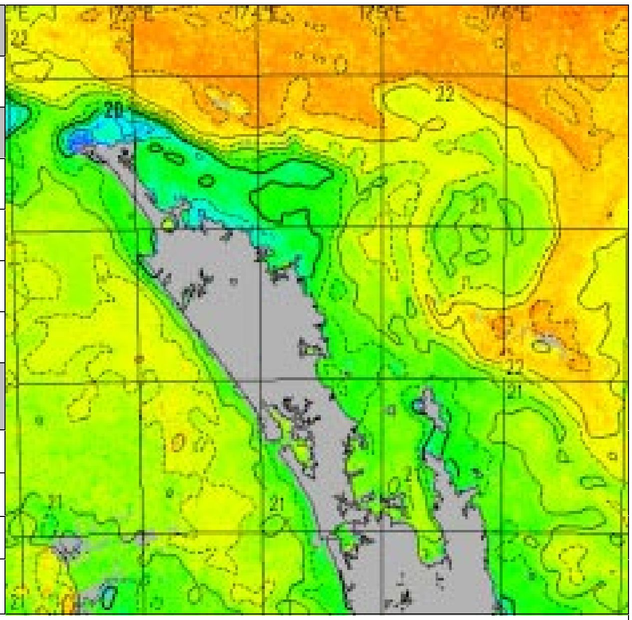
5.4 Recommendations

In this section a number of issues have been summarised and conclusions made. In many instances recommendations have also been made. In summary, this review has recommended that:

- funding in this Output continue to be increased for the near future, to ensure that the benefits available to the country from the increased revenues available to this industry are realised
- priorities for funding be changed to encourage research which will support the industry in satisfying non-tariff barriers
- research into new products based on fish waste become a higher priority, to realise greater value from our natural resources and further reduce the negative impacts on our environment of fish waste
- mechanisms for users to locate scientists be improved, to further improve access, communication and the identification of opportunities
- more emphasis be placed on publicising research activity via popular articles and other means more suited to the end-user community, to further improve the effectiveness of knowledge transfer
- ways be found to improve the realisation of commercial opportunities utilising the physical and intellectual assets created through research programmes.

Case Study 1: Remote Sensing of Fisheries

5.5 Overview



Lead Scientist	
Dr Michael Uddstrom	
Organisation	
NIWA (Wellington)	
Start:	1994
Completion:	2000
PGSF Contracts:	CO1430, CO1503
Funding to date ($ million)	
PGSF:	$0.94
NSOF:	$0.14
Other:	$0.46 (NIWA resources)
Future:	$0.5 (estimated)

This programme is developing techniques to locate wildstock fish concentrations using satellite borne sensing systems, and to provide location information to fishers.

The programme is based on the hypothesis that pelagic fish and some demersal species (squid) aggregate near ocean fronts caused by upwellings of cold nutrient-rich water into the sunlit zone, and that these fronts may be detected using sea temperature, sea surface height, wind and ocean colour data. Methods have been developed to process satellite data, making allowance for cloud cover. The satellite data has been collated with industry fish catch data (via the Ministry of Fisheries) to prove the hypothesis.

A process for creating and disseminating sea temperature charts has been developed. Scientists have demonstrated the use and viability of these charts on board vessels, presented the service to a range of fishing companies, and further publicised the service through roadshows and industry magazines. Sea temperature charts are now available on a daily basis via the internet and fax-back, and are increasingly used by fishers who appear to regard this as a valuable service.

The on-going programme will develop useful relative fisheries potential models and guidance maps for several species of fish.

Inter-dependencies:	• Ministry of Fisheries – fisheries data • Satellite operators (NASDA, NOAA, NASA) – observation data • Fishing companies (Sealord, Sanford, Talley's and Sollander Group) – fisheries data; support in kind for exploratory expeditions
Related PGSF Programmes:	• Remote Sensing of Ocean Colour (16-6093) • Ocean Fronts: Contribution to Marine Productivity (16-5920) • Ocean Variability of Currents and Water Masses (16-5919)

5.6 Commentary

Initiation of Programme

Fishers harvesting wildstock pelagic and demersal species generally locate their fish using the skipper's knowledge and experience, supplemented by direct observation (aircraft) and guesswork. Fishing is competitive, and fish stocks are not increasing. Fishing is an expensive business, and the industry faces financial risk from uncertain returns on the increasing capital and cost involved.

Experience on US tuna boats suggested that species would be found within a certain temperature band in the sea, and fishers were therefore keen to find ways to locate areas of defined temperatures. Research supported this view, and also indicated that the food chain is based on nutrients that occur in ocean anomalies (upwellings of deep, cold water). Finding these became of significant interest to fishers, who began to use information from MetService, and to buy instruments that could read analogue data streams from satellites.

These tools have been found to have degrees of accuracy wider than the preferred temperature range of the target species of fish and cannot compensate for cloudy conditions, and are therefore of little practical assistance. MetService used algorithms that had become outdated after a change of satellite, until they were updated by NIWA under this programme. A range of basic research was needed to provide a service that would accurately report sea surface temperatures and anomalies over a large scale. Ministry of Fisheries (MFish) and NIWA scientists applied for PGSF funding for this research in 1993.

Programme Elements

Scientific activity has so far been in three main areas:

– generation of the required data sets

  Considerable effort has been applied to the extraction and quality control of high-resolution catch and effort data and observed longline data from MFish. Similar effort has been applied to retrieve validated sea surface temperature and ocean anomaly data from high volume satellite data streams and to processing several terabytes of historical satellite data. PGSF support was used for the development of advanced cloud detection and sea surface temperature algorithms.

– data analysis and exploratory model development

  Systems have been established to manage and visualise large volumes of data, and oceanographic information has been extracted. The data has been analysed to demonstrate, for example, strong coherence between sea temperature and surface height. Processing systems have been established to integrate and visualise temperature, surface height, wind and fisheries data sets, and from this to specify oceanographic spatial features.

– communication with fishers

  Sea surface temperature information at 1 km resolution has been provided in chart form to fishers since September 1996 via fax and the internet. Scientists visited the major fishing companies and consultancies to discuss and demonstrate results from the research. Popular articles have been published in industry journals, a number of conference presentations have been made, and papers have been submitted to refereed journals.

Further scientific activity will develop a hierarchy of predictive models for particular species, focusing on those that are high value to the industry or have significant potential for development. The models will determine relative fisheries potential for each species for current or expected sea conditions, and will be evaluated through exploratory fishing.

Interdependencies and Collaboration

The programme has involved use of MFish data, and access to satellite signals from European, Japanese and American organisations. Programme scientists now have Principal Investigator status on the ERS, ADEOS (one of only 20 proposals selected) and SEASTAR missions, which assures them of access to satellite signals and science developments. To assist with the evaluation of ocean colour data, a specialist was hired from the Plymouth Marine Laboratory.

NZ fishing companies provide access to their catch records, and five committed their support to the 1997 funding application through making their vessels available for exploratory fishing operations.

This programme inter-relates with other PGSF supported programmes for supply of ocean colour data, observations on ocean currents, and ocean anomaly data and wind information. It also supports related weather, climate and oceanographic programmes that rely on satellite data.

Funding

The programme has been funded to $1.4 million from the PGSF (including the current application), and has benefited from $140 000 of NIWA's NSOF. NIWA has also contributed staff time to the value of about $460 000, for developing/reprocessing the SST datasets, developing associated software, downloading and processing satellite information and developing the graphical presentation formats used. The programme uses a dedicated satellite ground station, installed by NIWA at a cost of about $200 000.

The programme benefits from free access to satellite signals, which would cost about $0.5 million per annum (at current exchange rates) for commercial use.

The programme is being supported in kind by fishing companies through use of their vessels at no charge. It uses data collected by the MFish Quota Management programme, which is itself funded by a levy on the industry. The industry is now providing direct support because it is clear that the programme is likely to be successful and create value – it was initially seen as a high risk for investment.

Physical and Intellectual Assets Created

The programme has contributed to a variety of significant assets being created, including:

– innovative radiometer cloud detection methods and algorithms, and new sea surface temperature algorithms and methods for validation using buoys
– quality controlled data sets including the location of tuna caught from observed surface longline sets; catch per unit effort for squid; sea surface temperatures at 1 km resolution covering much of the South Pacific since

1995 (and earlier, by re-processing archived raw satellite data); sea surface height and surface geostrophic current anomalies since 1993 for the NZ region; marine winds; conductivity temperature and depth (from NIWA and MAF archives); ocean colour

- technology used for satellite download, data storage, data analysis and modelling, chart production and dissemination
- knowledge, skills and expertise gained by the scientists involved
- a capability to utilise new and existing satellite remote sensing technologies for oceanographic and fisheries research
- processing systems to integrate and visualise the various data sets, to specify oceanographic spatial features, and to deliver these to end-users
- modelling systems to predict relative fisheries potential for a number of NZ species (currently being developed)
- enhanced local and international reputations, of scientists, research institutes and NZ science capability in general.

Knowledge Transfer (Involvement of End-Users)

Knowledge transfer has been effected through:

- visits by programme scientists to nine major fishing companies and one fisheries consultancy to discuss and demonstrate results from the research
- preparation of the 1998 application for PGSF funding after considerable consultation with the industry, and after taking due note of the draft strategic research plan prepared for the industry by SeaFIC in 1997
- discussions with industry sector groups, fish processors and fishing companies, enabling the research team to develop close linkages with a number of key end-users, many of whom enthusiastically supported the 1998 application
- provision of a variety of information to fishers via fax, the internet and industry magazines, including fisheries guidance information, historical monthly mean ocean temperature maps and anomalies (to assist fishers plan the deployment of their vessels on a seasonal basis), and relative fisheries potential maps. Views obtained from users of these services were positive
- demonstration of fax and internet-based services at roadshows, during industry conferences and on-board fishing vessels
- publication of popular articles in industry magazines.

The internet site is heavily used by commercial and recreational fishers, and anecdotal evidence suggests that boats of the larger companies do not now leave port without having made use of the service. The smaller companies still, however, do not seem to appreciate the significance of the greater accuracy of the NIWA service compared to their alternatives.

Outcomes of the Programme

This programme was expected to provide economic gains to NZ through improved wildstock catch efficiency, and it was hoped that the overall catch would be increased through the identification of new fishing grounds:

– Nine fishing groups and companies, with a collective take of about 90% of NZ's annual wildstock catch, explicitly refer to improved catch rates and catch efficiencies as a result of information currently available from this programme, although the extent of the improvement is regarded as commercially sensitive. All supported the 1998 PGSF application, and five committed support in kind (use of vessels) worth about $1 million

– Tuna fishers indicate that skippers now rely heavily on the information, and refer to increased length of season and increased total catch specifically due to use of the charts. Australian fishers have also been making use of the service

– MFish believes that it has access to better information with which to manage quotas for the species affected by the programme

– significant intellectual assets and scientific capability have been created, particularly including the capability to utilise information obtained by satellite. The primary reason for NIWA's investment in this area is that many programmes will use satellite information in the future. This is already happening in oceanography, and will occur in other areas such as weather forecasting and coastal hazards.

Conclusions

PGSF has been used in conjunction with other sources of funds to create a service that is already of significant value to fishers, and to build an important platform for NIWA's use in other scientific activity.

Current charges for the commercial provision of SST charts recover delivery costs only. It is NIWA's intention to assess, towards the end of the current development phase, the robustness of the SST service, the bounds of its applicability, and its viability. At that time it may be transformed into a fully commercial service.

6. Optimising the Value of Seafood Products

6.1 Overview

<table>
<tr><th colspan="2">Lead Scientists</th><td colspan="4" rowspan="8"></td></tr>
<tr><td colspan="2">Dr Grant McDonald
Alistair Jerrett</td></tr>
<tr><th colspan="2">Organisation</th></tr>
<tr><td colspan="2">Crop & Food Seafood Group (Nelson)</td></tr>
<tr><th>Start:</th><td>1991</td></tr>
<tr><th>End:</th><td>Ongoing</td></tr>
<tr><th>PGSF Contracts:</th><td>CO2219, 2221; CO2406, 2407; CO2418, 2521</td></tr>
<tr></tr>
<tr><th colspan="2">Funding to date ($ million):</th><th>PGSF:</th><td>$3.3</td><th>Other:</th><td>$1.0 (industry)</td></tr>
<tr><td colspan="6">When industry earnings began to suffer because of poor product quality, researchers began to investigate. Their objectives were to determine how good a particular species of fish could be, and to develop knowledge and technology that could be applied by the industry to improve quality and optimise processing of seafood products. The research was soon reformulated into two complementary paths, investigating the effects of rested harvesting and processing.

Harvested fish has a short shelf-life, which is a major issue for an industry which freezes 94% of its catch for export to distant markets. Since very little was known about fish physiology, initial studies into processing focussed on the ‘gaping’ phenomenon that occurs as fish ages in storage. These studies identified rapid softening prior to gaping and, with the aid of purpose-built instruments for measuring tensile strength, developed a much better understanding of the processes at work post-harvest.

Research determined the effect of storage temperatures on these processes, and new post-harvest storage regimes were developed for use by the industry to minimise muscle softening (in hoki). Further research established seasonal variations in muscle proteins, which may prompt changes in fishing patterns. Handling techniques and processes are being developed for optimum quality, and researchers assist industry training organisations by establishing and updating course curricula and unit standards.

Research into rested harvesting was intended to develop mechanisms to reduce struggling during capture, which causes stress and bruising in the fish. Studies using farmed fish identified anaesthetics and developed handling regimes to minimise struggling, while meeting human safety criteria. These new products have been licensed for commercial development.

Researchers and industry have worked closely together throughout these programmes, and the Seafood Group is held in high regard by the industry.</td></tr>
<tr><th colspan="2">Inter-dependence and Collaboration:</th><td colspan="4">• NIWA (harvest quantities of Hoki)
• North Carolina State University (cryoprotection, etc)
• Oregon State University (seasonal changes in fish)</td></tr>
<tr><th colspan="2">Related PGSF Programmes:</th><td colspan="4">• Mechanisms of Autolysis (CO2622)</td></tr>
</table>

6.2 Overview

Initiation of Programme

Fishing is the last major food industry still based on hunting. The industry is highly seasonal, and experiences significant variations in the supply of its raw material. More than 90% of the catch is exported, and because of the distance from our markets the majority of the catch is frozen for storage and transport. By the end of the 80s it had become clear that earnings were suffering from perceptions of poor product quality in our major markets, and researchers began to investigate.

The researchers original objective was to determine and demonstrate how good a particular species of fish could be, which required control methods to test fish that had not been processed commercially. The initial research into measurement and control was reformulated into two complementary paths, investigating the effects of rested harvesting, and processing.

Salmon farmers supported research into rested harvesting, and the Hoki Management Company sponsored a joint project, involving industry staff and Crop&Food Seafood Group researchers, to investigate the handling of hoki (currently about one sixth of NZ's total catch, by value). With industry support, the Seafood Group applied for PGSF assistance for both streams of activity, and researchers have extended the scope of their work each bidding round since then. The fishing companies provided researchers with catch samples, access to their vessels, and staff to assist in some of the research activity, and funded related research.

Programme Elements

This set of programmes has a number of main elements, including:

– a study into the relationship between protein stability and processing variables

  Initial studies on salmon showed that rapid softening occurs before gaping becomes evident, and this was later found to be the case for hoki as well. A tensile test was developed to objectively measure changes in fish texture, and instruments were developed for use onboard vessels. Studies determined the loss of tensile strength and other changes during storage in ice and the effect of storage temperature on these processes. Research is continuing to provide strategic information on the effect of time, temperature and pH on fish quality, and provide a foundation for technologies that will support added-value processing.

– research into seasonal variations in muscle proteins

  Data collected onboard vessel indicated seasonal changes in hoki white muscle proteins, and similar variations in liver and gonads. Studies indicate that hoki have generally been caught during spawning, when their condition is at its worst, and indicate links between shelf-life, season of catch, and storage temperature.

– studies of the links between harvest-related stress and muscle softening

  Research into the capture process began using salmon, and strong correlations were identified between struggling caused by capture, the onset of rigor, and shelf-life after capture. An unexpectedly large degree of improvement resulted from establishing control over fatigue during capture, which suggested the possibility of a similar result for hoki - trawl-harvested hoki are exhausted during the capture process, and this has been related to rapid texture deterioration post harvest.

– identification of anaesthetics suitable for rested harvesting of fish

  During the studies into the capture process it became apparent that a reliable, food-compatible method of eliminating struggling during capture was required. Researchers identified and tested a range of suitable anaesthetic formulations, and developed humane administration and handling regimes intended to optimise results for the seafood operator.

– studies of the chemical and functional properties of proteins from fish by-products

  The lability of fish proteins and collagens is closely linked to habitat temperature, and as a result they have unique and useful functional properties. Research into these will support future development of added-value seafoods, using by-products that are currently wasted.

Interdependencies and Collaboration

Close collaboration has developed between Seafood Group researchers and scientists in the USA, particularly in cryoprotection and functional properties of proteins, and in relation to seasonal properties of fish. Other sections of Crop&Food do related research on proteins. The quota management programme and scientists at NIWA provide harvest quantity information. The Seafood Group contracts the University of Canterbury to undertake research related to physiology.

There has always been a close relationship between the Crop&Food and the fishing industry. One of the principal scientists joined the Seafood Group after working with Sealord, where he gained his initial interest in processing issues. He has also lived and worked in the USA and Japan, which has given him first hand knowledge of the market. Researchers have been employed by Sealord after leaving the Seafood Group. All the major fishing companies fund processing work related to the PGSF research on a project basis. All provide catch samples and access to vessels and equipment, and some provide staff to work for the researchers. Similarly, salmon farmers provided access to facilities and worked with scientists to develop rested harvesting management processes.

Funding

The programmes have received PGSF support to date of about $3.3 million, and research has benefited from industry support in kind and funding totalling about $1.0 million.

Physical and Intellectual Assets Created

The programmes have contributed to a range of assets, including:

– a centre of excellence in seafood quality and processing, recognised world-wide, capable of being applied to further species

– a facility in Nelson, based around a laboratory aquarium, able to take almost any species of fish, test rested harvesting handling techniques and technology, and establish benchmarks and control processes for the species

- a centre of excellence in cryoprotection as applied to fish and fish products
- new anaesthetic products, patented, branded and licensed to a company formed specifically to develop them commercially (Aqui-S New Zealand Ltd)
- a knowledge of protein technologies, which may become the basis of new revenues for the industry based on waste by-products
- a knowledge base in handling and processing fish, able to support the industry through changes in its structure and staff by serving as the repository of technological knowledge and best practice information.

Knowledge Transfer (Involvement of End-Users)

The close contact between the Seafood Group and the industry comes in several forms:

- industry representatives maintain an advisory group which meets with lead scientists biannually to discuss progress and issues. This group assists Crop&Food with its research strategy, reviews and endorses applications for PGSF support, and generally serves as a high level reference group for the industry and Crop&Food
- Crop&Food created a joint venture to promote the Aqui-S anaesthetic products. This company sells the products to end-users, advises on their use, obtains the necessary regulatory approvals, and contracts Seafood Group scientists to carry out further or related work if necessary
- the Seafood Group maintains close contacts with research officers and key technologists of the larger fishing companies, with scientists available to advise on industry issues at a moment’s notice. Success with these companies has encouraged smaller companies to follow suit
- scientists worked closely with the Nelson Polytechnic School of Fisheries to establish curricula and unit standards for processing and catch related courses. They continue to be closely involved with both the school and SeaFood Industry Council’s training organisation, assisting with updates of course material and by presenting to students
- scientists also work with suppliers to the industry, in specifying equipment which will support the handling regimes being defined
- the Group holds or presents at workshops, presents specifically to companies and quota groups, and provides posters and speakers at SeaFIC meetings.

The close interaction with industry brings with it risks of ‘capture’ by individual companies, who may contract the Seafood Group for research which will be confidential to themselves. The PGSF serves as a way of managing this, by ensuring that generic research benefits the entire industry.

One of the lead scientists sits on an advisory group for the International Institution of Refrigeration (IIR), which develops codes of practice and regulations affecting transport and storage of frozen or chilled product. This role serves to protect NZ interests by ensuring that trade barriers imposed through this body do not disadvantage our industry.

The recently proposed requirement that fish be transported at –1.1^{o}C would have eliminated all recent gains in quality and put our entire export industry at risk –

research indicates that storage at –4°C instead of –2°C may increase the shelf-life of hoki products by more than five times.

Outcomes of the Programme

These programmes have achieved significant economic, social and ethical gains for NZ:

- the industry has been made aware of the quality potential of its products, and shown how to achieve that potential. Hoki, which was once considered second-rate, and has only been caught since the collapse of NZ's inshore fishery, has now become our major export species
- the hoki industry has achieved gains in quality which have enabled it to hold its position in world markets during the recent downturn, while its nearest competitor (pollock) has lost market share
- information on hoki has enabled differentiation in the market, and assisted the establishment of a niche market for the species
- the industry has been made aware of the potential quality of their catch, and shown how to achieve that. The outcome has been that greater value has been gained from the stock and there is considerably less volume of waste
- our salmon industry has also maintained its share of the market and is expanding production despite intense world-wide competition, while Canadian product (which is the same species) has lost considerable market share
- the perception of NZ fish products in our major markets has improved – NZ is now perceived as bringing higher quality fish products to the market
- there is a perception world-wide that NZ are leaders in fish processing techniques and technology, which is encouraged by organisations such as Sealord establishing or taking over offshore facilities. Sealord are very conscious of this, and take legal steps to protect their advantage internationally (they will not install their technology in certain countries!)
- the IIR presence protects NZ trade interests. The standing of NZ scientists and their science enabled them to prevent regulations being established which might have eliminated our seafood export industry. This outcome alone justifies public expenditure in this area
- current research into labile proteins from fish processing by-products will enable new products to be developed and reduce wastage from processing. The current position in this research can be compared to that of the dairy industry 30 years ago when research was determining the seasonal changes in milk composition. That research continued, and underpinned the development of the lucrative functional dairy protein industry. A similar outcome is possible from current research
- protection of the hoki industry through improvements in quality has the social outcome of protecting employment in the West Coast, a region which currently has high unemployment
- the AQUI-S™ anaesthetic products minimise stress in fish, allowing humane and safe handling and euthanasia, which is an increasingly important ethical and marketing issue.

Conclusions

The use of a joint venture company to handle and commercialise the Aqui-S products appears to be a successful method of protecting intellectual capital and separating commercial interests from research interests, although it appears that there was considerable debate on the issue within Crop&Food before the strategy was approved. The companies that collaborated with Crop&Food recognise that the technology has created value for them, but are concerned that they may lose their current technological advantage if the products are marketed world-wide. It appears that the industry (and the Seafood Group) has learned their lesson, and all are much more conscious of the need for formal agreements relating to intellectual property before entering into research and development projects.

The success of these programmes takes attention away from the many dead-ends reached by researchers. It can take years just to define a problem, let alone find answers. When research began into processing, industry thought they were already doing as well as they could – the researchers had to demonstrate that substantial improvements in quality were in fact possible. Companies are generally unwilling to invest in these circumstances, particularly if their competitors will also benefit from a successful outcome.

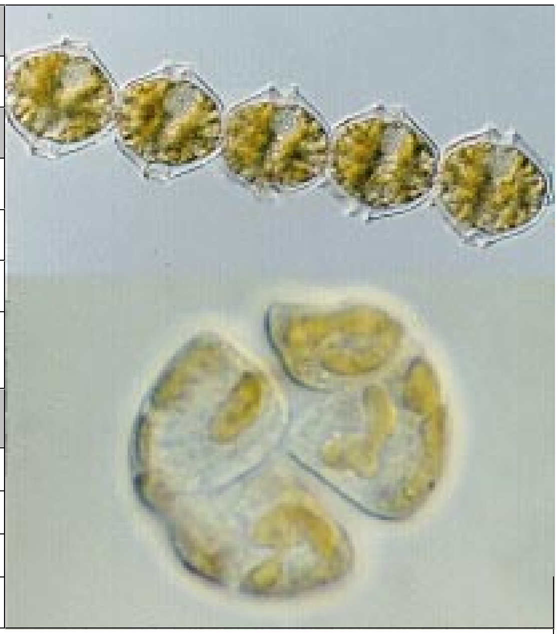
The programmes were adversely affected in the beginning by the short-term view held by the industry (on profitability), by its lack of time and resources to investigate, and by the lack of effective industry groups. Field trials of rested harvesting techniques were done with several companies, but only one had sufficient interest in quality (in contrast to human convenience), realisation of the significance of technology, and motivation to succeed with the concept.

These programmes can be characterised by the care in which the researchers have observed the spirit of public funding, while working under contract for companies in applications of the basic, public-funded research. Use of public funding in this case has enabled researchers to avoid capture by individual companies, and ensure that more of the industry is able to benefit.

7. Toxic and Noxious Algae

7.1 Overview

Lead Scientist	
Dr Lincoln Mackenzie	
Organisation	
Cawthron Institute (Nelson)	
Start:	1994
Completion:	2000
PGSF Contracts:	CAW301,601
Funding to date ($ million)	
PGSF:	$2.6 (to 2000)
NSOF:	N/A
Other:	$0.2 (MFish, TBG, Lotto)
Future:	



These programmes assist the shellfish and aquaculture industries avoid potentially disastrous effects of toxic and noxious algae, including mass mortality of shellfish and fish, poisoning of consumers, and loss of confidence by markets in NZ product.

Research into marine biotoxins has identified a variety of new phenomena and new toxic organisms and contributed to a more comprehensive understanding of the ecology of the micro-algae involved. It has enabled the isolation and culture of these organisms, and now a unique culture collection is maintained to support ongoing research in NZ and abroad. Research is also leading to the development of cheaper techniques to identify toxic cells in natural water samples, and to improvements in management systems intended to minimise the risk of intoxication in commercial farming.

Close contact and frequent communication is maintained between the industry, regulators and public health agencies, and regular feedback has enabled rapid identification of knowledge gaps and establishment of priorities. Scientists have disseminated their findings via numerous scientific papers, popular articles and presentations at conferences and seminars.

The general public has derived considerable benefit through the development of a more cost-effective monitoring regime involving recreational and customary fishing as well as commercial fisheries. The programme has also enabled the development of a world-leading capability that has enhanced the reputation of NZ science.

Inter-dependencies:	• Crop&Food • Ag-Research • ESR • NIWA	• Univ. of Auck/Otago/Cant • Univ. of Tohuku, Japan • Monterey Bay Aquarium RI, USA • Inst. Marine Biosciences, Canada
Related PGSF Programmes:	• Coastal and Estuarine programme (CAW607) • TBG programme (FIB501)	

7.2 Commentary

Initiation of Programme

In 1983 a shipment of shellfish to Japan was rejected for toxicity reasons. The Fishing Industry Board approached Cawthron for advice, and as a result sponsored the attendance of Dr Mackenzie at a conference on marine biotoxins in Japan in 1984. This visit sparked active research into marine biotoxins in NZ, and helped establish good contacts with Japanese researchers. In 1989 an algal bloom in Big Glory Bay almost wiped out the emerging sea-cage salmon farming industry. As a result, the industry funded a toxic phytoplankton monitoring programme in salmon farms throughout the country, following advice from Cawthron, which began to carry out low level research activity as part of an existing coastal and estuarine ecology research programme.

Cawthron scientists, aware of the significance of this issue, applied for PGSF support in 1993 for a stand-alone programme focussed on toxic and noxious algae. During the bid assessment process a large and widely publicised algae bloom occurred in the North Island, resulting in human death and economic damage to the shellfish industry, and the bid was successful. Additional funds were obtained via Lotto (for equipment), and collateral support came from a MAF operational research project for the design of a nation-wide monitoring programme. Working relationships were established with ESR and Ag-Research, which used NSOF resources (and later PGSF) for toxin analysis and biochemical detection programmes respectively. Crop&Food were later awarded PGSF for a research programme on toxin depuration, and the University of Auckland were funded for the development of molecular probes for monitoring purposes (using Cawthron cultures). Close co-operation and collaboration developed between Japanese and Cawthron scientists, with the former making several major discoveries due to the NZ links.

Programme Elements

Scientific activity has been focused on several areas:

– the creation and maintenance of a culture collection of toxic/noxious micro-algae

  In 1993 no algal specimens were being kept alive. The development of a culture collection as a reference and resource for research was essential. Skills and techniques were developed for identification of the organisms, and research into their toxicity and physiology led to a better understanding of optimal growth conditions. A sophisticated culture room was built, providing facilities and security as appropriate for toxic organisms, and procedures have been developed for secure transport of specimens to users. An extensive collection of identification manuals is maintained, in collaboration with other culture collections around the world.

– studies of the taxonomy and toxicity of the two major species (*Alexandrium, Gymnodinium*)

  These two species are known to be significant in a high proportion of NZ incidents. The studies are intended to identify the biological and environmental factors responsible for the proliferation and toxicity of these organisms. Cultures of live toxic species are required for the fabrication and testing of new generation genetic probes, which will lead to improved (and potentially automated) identification of toxic cells in natural water samples. Research into *Gymnodinium* is providing the knowledge necessary to produce more accurate methods of recognising and counting cells in natural water samples.

– studies of other species, and identification of species affecting Northland estuaries

  Several species, newly discovered through the programme, are being studied, and research undertaken to identify and study an unknown species that may be the source of the chronic toxicity found in Northland shellfish.

– development of alternative tests for biotoxins (to replace mouse bioassays)

  Research into the fate of biotoxins in shellfish will lead to the development of alternative tests as regulatory methods, to reduce the current reliance on mouse bioassays, which is subject to increasing pressure from ethical considerations, cost and uncertainty of interpretation of test results.

Interdependencies and Collaboration

This research involved extensive collaboration between NZ and offshore research institutions. Japanese institutions, which led the world in shellfish toxin research, became involved originally as investigators on behalf of Japanese regulators assessing NZ product reaching Japan. These institutions now work actively with Cawthron to identify toxins, and the collaboration has extended to include Australian, Canadian, USA, Korean and Danish institutions. Culture activities and results are shared with the other large collections in Japan, Europe and the USA, and Cawthron now sends samples all over the world. Cawthron and American researchers are currently working together to adapt American gene probe technology to NZ conditions.

The phytoplankton monitoring programme involves Cawthron, the Ministry of Health and various Crown Health enterprises, MAF and the industry, all of whom work closely together. ESR, Ag-Research and the University of Otago research new assay methods for use in the programme, NIWA and University of Auckland research ecology and molecular taxonomy respectively. NIWA provides further assistance by describing the oceanographic conditions prevailing during bloom events, and Crop&Food research toxin depuration. This activity is co-ordinated through a national Marine Biotoxin Management Board, Marine Biotoxin Science workshops, and meetings of technical committees.

Although industry has provided no direct financial support for the research, their expenditure on monitoring provides samples and data that identifies toxicity events, enabling researchers to direct their efforts towards these.

Funding

Research in this programme has been funded largely by the PGSF, although the CRIs involved (Ag-Research, ESR) used some of their NSOF allocation to initiate their contribution to the programme. The Fishing Industry Board obtained TBG funding which enabled Cawthron to do crucial research into the link between toxin-producing phytoplankton and toxicity in shellfish, and some funds for essential equipment were obtained from Lotto.

The research programme had a slow start, which is perceived to be due to a lack of flexibility in the 1993 funding round of the PGSF. Had there not been an application already in the system when the 1993 bloom occurred, very little research would have been carried out until after the next round, two years later.

Industry, via the Mussel Industry Council, decided to fund the phytoplankton monitoring programme in parallel with the existing flesh-testing regime because it appeared to offer some possibility of reduced testing costs in the future, which enabled the research programme to develop. The Council and some companies have also supported and funded related projects.

Physical and Intellectual Assets Created

A number of assets have been created through these programmes, including:

– the largest culture collection of toxic and noxious algae in the world (almost twice the size of any other), including identification manuals and relevant documentation

– the capability to maintain an extensive culture collection, provide samples to other researchers, and maintain the identification manuals required

– research group expertise and capability, held in high regard internationally. Two Cawthron staff have been put through PhDs on the programme; three other PhD and two MSc candidates have had substantial assistance

– enhanced reputations of the scientists and Institutes involved, and of NZ science in general, which is of particular importance in support of NZ's position in relation to existing or proposed phyto-sanitary trade barriers

– a significant knowledge base of the content of natural waters (endemic and introduced)

– a commercial monitoring capability, providing services to industry and regulators.

Knowledge Transfer (Involvement of End-Users)

Close contact has been maintained between Cawthron scientists and the fishing industry, and close collaboration continues between all the scientists involved in this research.

Almost daily contact by researchers with industry, regulatory and public health agencies has greatly assisted the identification of issues, priorities and gaps in knowledge. Liaison between researchers from various organisations has assisted the development of this and related research projects, and resulted in co-ordinated projects to make best use of existing science capabilities.

The findings of this programme have been disseminated by a variety of means, including:

– more than twenty scientific papers in refereed journals, about thirty popular articles in industry magazines, more than twenty presentations at conferences, seminars and talks to public and professional groups

– participation in biannual Marine Biotoxin Science workshops and meetings of technical committees involving officials, scientists and industry research officers

– participation in reviews by officials of the US FDA during their annual visits to NZ

- use of the Cawthron biotoxin monitoring service to educate and update the industry
- free access to the media for Cawthron researchers, presentations in schools, etc.

Cawthron faced a considerable challenge in persuading regulatory agencies and the industry that it was feasible to rely on water-based testing rather than flesh testing. The shellfish industry still has to convince international markets and regulators.

Outcomes of the Programme

This programme has achieved substantial **economic** and **social** outcomes:

- the cost to the industry of monitoring for biotoxins has been reduced by at least $0.25 million per annum, and similar costs to the public health system have been reduced by more than $2.25 million per annum from 1993 levels.

  NZ is in the unique position of having to test for four groups of toxins (most other countries are only affected by one or two groups). Initial testing regimes required sophisticated laboratories, making monitoring expensive
- shellfish industry revenues (currently about $120 million annually) and employment have been protected against losses due to biotoxins by the monitoring programme and the change in attitudes within the industry brought about by a greater understanding of the issues. The Big Glory bay disaster cost about $17 million and several jobs
- regulatory activity is now based on a much better understanding of the issues. The 1993 closure of the Marlborough region (for three months) resulted in a significant loss of market confidence and revenues, but was not necessary – not all algal blooms are toxic
- NZ has earned respect and a relatively secure position in world markets for shellfish
- the risk to public health has been dramatically reduced due to an enhanced awareness of shellfish and algae, and the biotoxin monitoring programmes
- with greater awareness of the role of algae has come a much better understanding of the need for clean water to maintain a healthy growing environment for shellfish and farmed fish
- Cawthron has built a capability to carry out related research into related biosecurity issues such as the effect of ballast water on the NZ environment and the impact of vessel movements on marine environments in ports
- Cawthron has established a commercial monitoring service, which has revenues in excess of $0.1 million, but which is only just able to cover its operating costs
- ethical issues related to flesh testing of shellfish by mouse bioassay have become less significant. The ability to rely on phytoplankton monitoring in water (until toxin levels reach predetermined trigger points) has reduced the need for flesh testing considerably. The development of alternative tests has also reduced the need for mouse assays

– NZ scientists involved in the programme are regularly asked overseas to assist taxonomy or research into toxins found there, which demonstrates their pre-eminent position in the field.

Conclusions

PGSF funding for CAW601 ends in June 2000. A decision will have to be made at that time whether this unique capability should be maintained. If it is not, the researchers involved will move to other tasks and some may choose to take up positions overseas to continue their work. If there is no continuing long term funding, Cawthron will have to attempt to support the culture collection from other sources.

Cawthron does not receive the NSOF allocation that a CRI might use for this purpose.

8. Sustainability of Cultured Shellfisheries

8.1 Overview

<table>
<tr><td colspan="2">Lead Scientist</td><td colspan="2" rowspan="8"></td></tr>
<tr><td colspan="2">Dr Mark James</td></tr>
<tr><td colspan="2">Organisation</td></tr>
<tr><td colspan="2">NIWA</td></tr>
<tr><td>Start:</td><td>1994</td></tr>
<tr><td>Completion:</td><td>2003</td></tr>
<tr><td>PGSF Contracts:</td><td>CO1431,
CO1604</td></tr>
<tr><td colspan="2">Funding to date ($ million)</td></tr>
<tr><td>PGSF:</td><td>$0.9</td><td>NSOF:</td><td>$0.12 (programme start)
$0.1 (Visiting Scientists)</td></tr>
<tr><td>Other:</td><td>$0.8 (Mussel Industry, TBG, MSSQP)</td><td>Future:</td><td>$1.0 (4 years of PGSF)</td></tr>
</table>

Four elements stand out in this case study:

1. The requirement for science based information came from rapid development of a major seafood industry for New Zealand – and from what had to be a renewable, and therefore sustainable resource, and was identified as a priority by the industry.
2. The information required was predominantly at a larger spatial scale than the individual farm. It was also information for which there was a wide base of stakeholder beneficiaries. These beneficiaries included resource planners, aquaculture industry as a whole, and the wider community.
3. The programme evolved from small beginnings funded by the Public Good Science Fund. Its current success has been made possible by complementary funding support from a wider range of resources that far outstrip the PGSF funded input.
4. NIWA is now working with and co-ordinating an impressive range of companion resources, including new graduates and some overseas based inputs.

The models produced by the science programme have defined the key parameters affecting the carrying capacity within embayments. The models have been developed in one embayment, but are transferable to other regions. Ignoring the impacts identified could have put this $100 million industry at economic and sustainable risk. Current PGSF support represents just 0.25% of net revenues of this developing industry.

Inter-dependencies	• Cawthron Institute • University of California, Santa Barbara, USA • Sealords Shellfish Ltd. • Sandfords Ltd • Mussel Industry Council • Marlborough Sounds Shellfish Quality Programme (MSSQP) • Proudman Oceanographic Lab. UK • Plymouth Marine Lab. UK
Related PGSF Programmes:	• Vertical Processes & Phytoplankton Dynamics (CO1630) • Biological Effects of Cross-shelf Transfer (CO1619) • Benthic & Planktonic Microalgae (CAW204, 505, 607)

8.2 Commentary

Initiation of Programme

The need for this programme was recognised by the industry, and using the Mussel Industry Council as the vehicle, a wide range of stakeholders have been brought together. NIWA, the primary science provider, co-ordinated a diverse range of scientific resources.

The development of the Greenshell™ mussel industry has been the dominant thrust of New Zealand's aquaculture industry. In 1994, with approximately 400 shellfish farms in the Marlborough Sounds, concerns were expressed by the industry and local councils that farming in some bays was close to capacity. New proposals were being put forward for blocks of up to 1,000 hectares, but at that time New Zealand did not have data which could predict the impact and sustainability of developments on such a scale.

It was known that each mussel can clear up to 200 to 300 litres per day and commonly five litres per hour. In the bay selected for study, Beatrix Bay (Pelorus Sound), mussels farmed were capable of filtering the total capacity of the embayment in 40 to 80 days. With flushing times up to 20 to 40 days in some bays, some depletion of food was likely.

Hydrodynamic simulations now indicate that the tidal flushing of Beatrix Bay occurs in 16 tidal cycles (8.3 days). There are a number of other variants that determine sustainable capacity, and Figure 8.1 and Figure 8.2 show the six science sections that make up the full carrying capacity model.

Programme Elements

The initial task was to come up with models that would identify key factors affecting sustainability. The team started with mussel farming, selected an embayment in the Marlborough Sounds to develop and test the models and then looked at key environmental factors. Specifically, they sought to determine what influenced the availability of food and how the mussels utilised that food. The research was directed at the embayment scale but also incorporated work at the farm scale level.

In simple terms, the programme development sequence was:

Year One Identify the factors influencing sustainability.

Year Two Develop models, to be robust and the basis for predictions

- A. Hydrodynamics – flushing of the bay, circulation and flow patterns, etc., and how this related to food supply
- B. Ecological factors affecting food for mussels
- C. Mussels population structure and energetics i.e. how mussels utilise the food
- D. Combine models into a carrying capacity model.

The science work was intended to estimate carrying capacity by determining the:

- harvest tonnage that could be taken out of embayments at different stocking levels
- growth time to harvestable size at different stocking levels.

Initial simulations were over a three-year period. Since 1995 environmental variables have been monitored and recorded two-weekly. This data now provides the basis to look at how the simulations match observed data. The team is now adding rainfall and river flows data to correlate environmental data, food supply and mussel condition and growth.

Funding

The programme was funded from PGSF and NSOF:

1994: $208K – one year (first year)

1995/96: $187K, plus $115K from NSOF for one year

1996: $250K for six years

In 1998 the programme was combined with a related programme in Output 16 to form a new programme 'Sustainabliity of Coastal Ecosystems and Cultured Shell Fisheries'.

Knowledge Transfer (Involvement of End-Users)

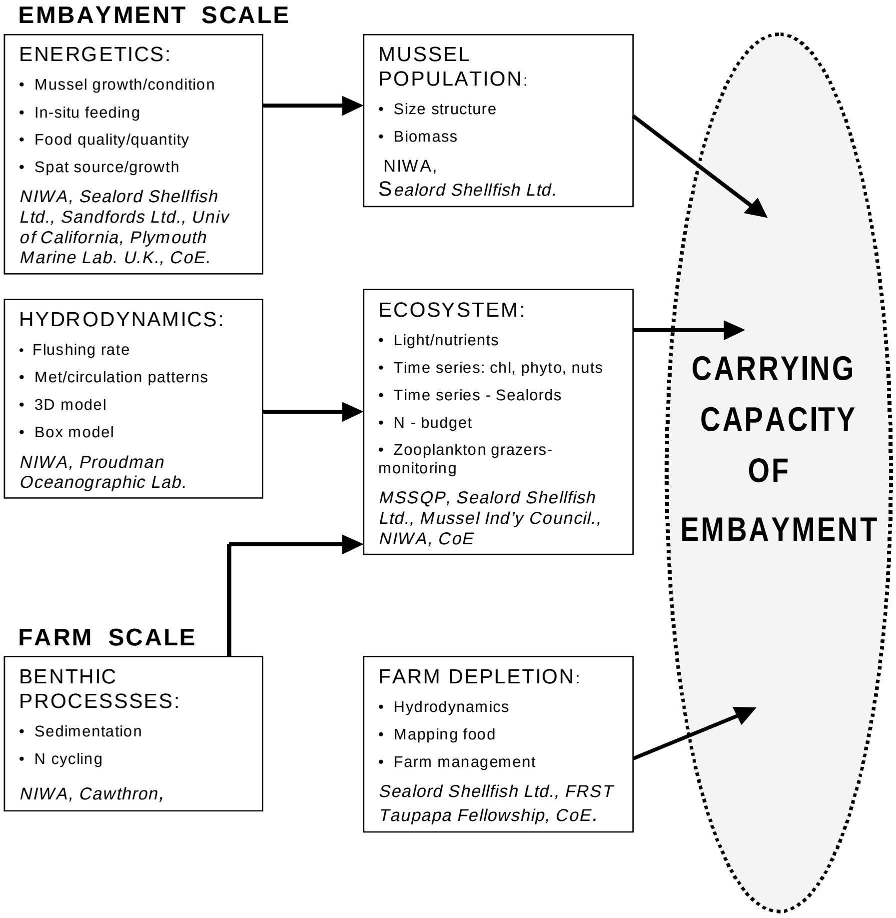
In many instances, the end users were, and still are, participants in the programme. The diagram and table on the following two pages show the wide range of organisations that contribute to and benefit from the integrated programme.

As the programme was initiated by the industry, it has, through the Mussel Industry Council and major participants, been continuously involved in management input, data collection and transfer of findings to industry participants and resource managers.

Interdependencies and Collaboration

Figure 8.1 illustrates programme sub models and extent of collaboration involved:

Figure 8.1: Collaboration in this Programme



MSSQP = Marlborough Sounds Shellfish Quality Programme

CoE = University of Canterbury / NIWA: **Centre of Excellence** in Aquaculture and Marine Ecology.

Figure 8.2 schedules the roles of the many stakeholders involved in this programme:

Figure 8.2: Stakeholder Roles

TASK:	CARRIED OUT BY:	PURPOSE:	FUNDED BY:
1995 onward	(MSSQP = Marlborough Sounds Shellfish Quality Programme)		
Develop models	NIWA & visiting scientists	Start development of models	NIWA Visiting Scientist Programme, MSSQP, PGSF Output 6, Industry levy.
Identify gaps	NIWA & visiting scientists	Identify gaps which need further work	
Start collection of time series	MSSQP, Cawthron, NIWA, Sealords Shellfish Ltd.	Collect environmental data to test models against	
1996 Onwards			
Population data	Sealords Shellfish Ltd, NIWA	Growth, condition data, size structure of population for model	Sealords Shellfish Ltd., PGSF Output 6, Industry levy, MSSQP

Collect time series	MSSQP, Cawthron, NIWA, Sealords Shellfish Ltd.	Collect environmental data to test models against	
1997 Onwards	(CoE = students with University of Canterbury / NIWA **Centre of Excellence** in Aquacultutre and Marine Ecology)		
Quantify sedimentation processes	NIWA, Cawthron Institute	Contribute to ecosystem model	PGSF Outputs 6 & 16
Determine effect of food quality / concentrations on feeding energetics	NIWA, Niwa Visiting Scientist Prog., CoE student	Parametise mussel energetics model	NIWA visiting scientists programme, PGSF Output 6
Collect environmental time series	MSSQP, Cawthron, NIWA, Sealords Shellfish Ltd.	Expand number of sites and environmental variables	Mussel Industry Council/Industry levy, PGSF Outputs 6 & 16
Collect data on zooplankton populations	CoE student, NIWA	Determine competition for resources	NIWA scholarship, PGSF Outputs 6 & 16
Examine spat sources–growth	CoE student	Find better way to manage spat sources	TBG, Sealords Shellfish Ltd
Determine farm scale depletion of food.	CoE student	Determine whether there is an impact at farm scale, better farm management	FRST Taupapa Maori Fellowship

Physical and Intellectual Assets Created

The most significant assets created by the programme are:

- The development of models for most aspects of farmed shell-fisheries
- The procedures and processes for obtaining data to run the models
- The ability to transfer and apply those models to other locations.

The intellectual assets now created include:

- A good understanding of relationships between environmental variables, mussel food and the impacts upon mussel growth and condition.
- Highly developed models tested in one embayment.
- Models that can now be tested at other locations after collecting data on water flow (hydrodynamics) and food levels (phytoplankton).

Outcomes of the Programme

The outcomes of this extensive programme include:

- Science significance: in the development of sustainable models and related knowledge
- Economic benefits: by determining the input upon productivity and maturity in farmed shellfish
- Social impacts: by recognising the implications on quality product and sustainability that can have social consequences. Location siting is an example.

To date, the models developed have demonstrated:

- slow growth of mussels at high stocking density as the phytoplankton become depleted – but other interactions, such as the competition between mussels, nutrient cycles and zooplankton grazers can have a major influence upon the ecosystem.
- the Greenshell™ Mussel can adapt very quickly to changes in food quality and concentration through pre-selection processes. A sudden increase in suspended sediments is an example.
- the possible consequences of over-intensive farming is a risk as the culture period could be extended from a one year cycle to a two year cycle with two periods of slow growth over winter. This occurrence would result in a sharp increase in the cost of production.
- an improved accuracy of estimation of the carrying capacity (sustainability).
- identification of portions of embayments with high and low current speeds that can effect the availability of food and thus mussel growth and condition.
- why 1995 was a good year for mussel growth and condition, but 1996 and 1997 were particularly poor and of major concern to the industry. The knowledge obtained can potentially provide a predictive tool for the future by linking findings to larger scale climate events.
- significant advances in the scientific understanding and knowledge of the environmental impacts of mussel farming. This knowledge is now being applied to the assessment of environmental effects for resource consents.

The value of the models now developed has been recognised by other industry sectors. As one result, the team now gets requests for data to evaluate environmental and economic sustainability of new and/or expanded areas. There has also been considerable interest from Australia and other Pacific countries such as the Cook Islands.

Next Step and Outlook

- Expanding sites to other parts of the Marlborough Sounds, Hauraki Gulf and to Stewart Island
- The oyster industry want to do similar work related to both rock and Pacific oysters.

Conclusions

- There is little appreciation among the public of the significance of our aquaculture farming. Consider the following comparison for two adjoining farms:
  - *Farmer 'A':* from 445 hectares (1,100 acres) of relatively steep land bordering the sea, has an annual production of 45 tonnes of beef (on the hook)
  - *Farmer 'B':* a marine farmer using 12 hectares (30 acres) has an annual production of 300 tonnes of mussels (meat weight)

  (As printed in 'Seafood New Zealand', July 1996, pp 53)
- Shellfish farms in NZ coastal waters do not share the same environment as other countries. In France, it takes up to four years to get oysters to maturity

– compared with 18 months when stocking levels were lower. In NZ, mussels reach harvestable size after 10 to 18 months.

- In 1994, the year in which the subject science programme commenced, NZ's mussel exports were worth approximately $70 million. Eighty percent of the industry is located in the Marlborough area. Total NZ production is now worth more than $100 million annually. Ignorance of factors now identified could have put this $100 million industry at economic and sustainable risk. Such an occurrence would also have had significant social and environmental implications.
- The funding of the original investigation and modest continuing funding from the Public Good Science Fund has been crucial in the achievements to date. Current PGSF support represents just one quarter percent of the annual gross worth of the developing industry.
- The models and results produced by the science programme have defined the parameters which affect carrying capacity within the sample embayment.
- Individual shellfish farm owners could not have undertaken the work. The environment goes far beyond the small confines of a single farm, and the selection of an embayment scale research area (above farm scale), has been effective.
- The task was not straightforward and the extensive participant involvement is a credit to the primary science provider.
- The team is now looking for even better ways to predict sustainability of the industry: economically and environmentally.
- The collective work of scientists and industry has produced innovative exciting science of international interest. This in turn enhances the standing of NZ as both producer and exporter. The knowledge itself is starting to become an exportable commodity with initial interest from farming groups in South Australia, Tasmania and also the Cook Islands.

9. Fishing Impact upon the Environment

9.1 Overview

Lead Scientist	
Dr Simon Thrush	
Organisation	
NIWA	
Start:	1994
Completion:	2004
PGSF Contracts:	CO 1429 CO 1502
Funding to date ($ million)	
PGSF:	$0.64
NSOF:	$0.02
Other:	$0.035
Future:	$3.0
Inter-dependencies	
Related PGSF Programmes:	CO1609 & NSOF NRG703; CO1517; NOSEX; CO1624; CO1618

Marine environments are dynamic and complex, the knowledge base is small, and many changes are not noticed until too late. Current concerns about sustainability, ecosystem management and maintenance of biodiversity emphasise the need to assess and manage environmental impacts of commercial fisheries.

Observations about marine environments are often at the wrong scale to identify connections between habitat features and the state of exploited stocks. Importantly, the resolution of these connections depends upon the constructive management of both fisheries and marine ecology.

The subject research investigated the physical and biological impacts of commercial fishing (trawling for bottom-dwelling fish and dredging for scallops) in the Hauraki Gulf and off the east coast of the Coromandel Peninsula.

Among the findings of this research, the most important is that commercial fishing for bottom dwelling fish and scallops has a significant impact beyond the removal of the target species. Broad scale changes in the ecology of the seafloor occur as a result of habitat disturbance by commercial fishing. Decreases in fishing pressure were directly associated with significantly higher densities of large surface dwelling animals and increased biodiversity. In addition, the trialing of a variety of modern sampling techniques to assess seafloor habitats at different resolutions has provided important information that can lead to the development of rigorous and rapid assessment techniques. These will eventually enable cost-effective monitoring and assessment of broad scale environmental effects.

9.2 Commentary

Initiation of Programme

This programme involved fundamental research on the seafloor habitats in near-shore marine environments, and was the first of its kind in New Zealand. It was initiated by the need to know what impact fishing was having upon our marine environment.

New Zealand has a vast fisheries area but little is known about it. There is a need to know just what ocean-floor life there is in the seas around New Zealand. Fisheries cannot be managed solely based on populations – they have to be managed by managing ecosystems to develop sustainable fisheries. Little seabed animals are often the main food sources of the main predators such as snapper, and they are also an important part of the ecosystem. Little is known about the interaction between the shellfish, worms, snails and other sedimentary life and the larger, predatory fish such as snapper, crayfish, hoki and orange roughy which feed on it.

The seabed is publicly owned, and the precautionary approach to environmental and fisheries management has been emphasised in the Resource Management Act and the 1996 Fisheries Act. The emphasis of the Fisheries Act however requires the gathering of appropriate information to identify changes in marine ecosystems over broad spatial and temporal scales to reasonably assess environmental risks to the sustainability of the ecosystem and fishery resources. But two aspects are highly relevant:

- research has not kept up with development in local fisheries
- resource managers do not adequately understand the real meaning of words used, such as sustainability and ecosystems.

Recognised Issues

During the 1960s the world's fisheries were seen as holding an inexhaustible supply of food. Now, no one believes this. In recent years, one after another of the world's major fisheries has collapsed or exhibited signs of severe stress. Fisheries all around the world are collapsing and what we urgently need to know is how we can manage our fisheries so that they are a sustainable resource. We do not want to shut the fisheries down, but we do need to find out just how they can be worked and managed so that we can continue to use them.

Focused on managing their stocks, fishery managers seldom look for the interactions between species. Marine scientists are sounding warnings over the impact upon the seabed where natural communities at the base of the food chain are being devastated by heavy gear.

Commercial fleets are increasingly investing in seabed equipment known as mobile gear. Dragged along the ocean floor at even the greatest of these depths, their trawls and dredges scoop up everything in their path, bringing to the surface whatever doesn't sift through their nets. Those nets inevitably snag some rocks, turning them over and destroying animals attached to them.

It is estimated that ten to twenty kilograms of these non-target animals, which are generally smaller than the target fish, may be caught – and discarded as waste – for every kilogram of commercial catch. Worthless by fishing standards, these creatures play an important role in marine ecosystems, both by adding significant levels of complexity to seafloor habitats and by providing a food source.

The destruction when a fishing boat trawls a net across the seabed is similar to that caused by a bulldozer blade scraping across land. The difference is that trawling does not require resource management consent. A single pass of the trawl can remove five to 20 percent of the seafloor animals. Total depletion can result from 10 to 12 successive trawls. Some argue that trawling's toll on these largely ignored seafloor species may underlie the recent collapse of many commercial fish stocks.

Programme Elements

The basis of the research was a three-year study of the seabed to ascertain the effect of commercial fishing on marine life in the ocean-bottom sediment. The area of the Hauraki Gulf chosen for the survey contained sections of seafloor heavily worked by trawlers and dredges, and also nearby areas (including the Leigh marine reserve) where there has been no commercial fishing.

The animals on the sea floor were sampled in three ways:

- Video surveys of the large animals on the sediment surface. The research involved diving and also use of side-scan sonar and a remotely operated vehicle (ROV) with video camera.
- Grab and suction dredge sampling to assess numbers and types of large animals (i.e., larger than 2 mm diameter) living in the sediments.
- Core sampling to assess numbers and types of small animals (i.e., larger than 0.5mm in diameter) that live in the sediment.

Also measured were a number of environmental parameters including sediment grain size, organic content, and water depth. Samples were collected from 18 sites in the Hauraki Gulf, which varied in depth (from 17 to 35 metres) and in sediment characteristics. Data were analysed using generalised linear modelling to test prior predictions of the relationship between fishing pressure and the types and the abundance of these seafloor animals.

Interdependencies and Collaboration

In 1997/98 the Department of Conservation funded a study to define habitats associated with a fishery reserve area in Hawkes Bay and identify broad-scale differences between fished and unfished areas.

Professor Paul Dayton (Scripps Institution of Oceanography, California, USA), participated in the programme.

Funding

Initial work began in 1994, with a Public Good Science Fund contract funded $159,000 each year for four years.

NSOF funding of $15,000 was applied to the programme in 1997/98.

Physical and Intellectual Assets Created

The programme findings have provided some of the strongest evidence available world-wide and thus have important implications for managing marine resources:

- Researchers in this programme have been among the first to demonstrate broad-scale changes in the ecology of the seafloor due to habitat disturbance by fishing
- The potential importance of changes in benthic communities due to habitat disturbance by commercial fishing is often discounted because impacts have not been well documented

  Biological effects are difficult to identify due to the complexity and variability in benthic communities. Combining modern statistical techniques with testing of prior predictions, the researchers were able to attribute broad-scale changes in macrobenthic communities to fishing disturbance. These effects were documented from a region that is locally important to coastal fishers
- Trialling a variety of modern sampling techniques to assess seafloor habitats at different resolutions (i.e., video, grab/suction sampling, core sampling) has provided important information which can lead to the development of rigorous rapid assessment techniques. This will eventually enable cost-effective monitoring and assessment of broad scale environmental effects
- As well as testing individual predictions, multivariate analyses of the seafloor communities were performed, based on either core or grab and suction dredge data
- After accounting for the influence of environmental variation, about 20 percent of the variability in the composition of the seafloor communities was attributed to habitat disturbance by commercial fishing. This is ecologically significant – especially considering the broad scale over which the survey was conducted.

Knowledge Transfer (Involvement of End-Users)

The initial need is for the merging of ecological research with management of fisheries.

An approach that emphasises gathering appropriate information to identify the way and degrees to which fishing changes marine ecosystems over broad spatial and temporal scale is essential to the identification of environmental risks to the sustainability of fishery resources and the ecosystems to which they belong.

A two-day workshop was held with end-users to discuss the findings and implications of this research, and to identify questions for future research. This was attended by representatives from the Ministry of Fisheries, Ministry for the Environment, SEAFic, Orange Roughy Company and the Auckland Regional Council. Further meetings were held with Ministry for the Environment, Hauraki Maori Trust Board, ECO, Royal New Zealand Forest and Bird Protection Society and Department of Conservation.

This research has also been discussed at a number of scientific meetings, and at research and management institutions around the world. Aspects of the research were also presented at a recent NZ conference designed to heighten public and political awareness of marine conservation.

Outcomes of the Programme

The outcomes of this programme have economic, environmental and social impacts:

- Today fisheries are managed largely in terms of how many animals can be harvested without reducing the vitality of the population. The data obtained provides evidence that the fishing industry needs to recognise these environmental impacts, and then act decisively to reduce them because fisheries are sustained by natural productivity. Adverse environmental effects may feed back to influence the sustainability of fisheries resources. Sustaining this industry while conserving marine resources will be a major challenge for fishers, fisheries and resource managers, and ecologists. This, in turn, has social implications when fisheries are no longer sustainable.
- In marine ecosystems, the removal of target and non-target species and habitat disturbance by commercial fishing are probably the most important human impacts.
- Perhaps the most ecologically important effects relate to changes in habitat complexity. The removal of organisms that add three-dimensional complexity to benthic habitats is potentially extremely destructive, as in the homogenisation of sediment characteristics by physical action of dredges and trawls.
- There had been a general recognition of the need to consider the ecological impacts of commercial fishing, but identifying impacts is often clouded by the lack of environmental impact assessment procedures in fisheries management.
- This new study on the effects of trawling and dredging raises questions about the extent to which commercially fished stocks depend upon habitats that are being degraded by seafloor trawling and dredging. The linkage is determined where the quality of the habitat is a direct contributor to juvenile fishing stocks and the mature stocks in subsequent years. Studies conducted overseas have demonstrated these relationships can occur, but we need to gather information for New Zealand's commercially exploited species to assess their significance in population stability.
- Large-scale impacts were demonstrated, and the observation made that these had a major impact on the marine environment in terms of killing organisms. With decreasing fishing pressure the scientists observed increases in the density of echinoderms, long-lived surface dwellers, total number of species and individuals. Many of the organisms that were removed were not the target species but they were potentially food for fish and provide habitats for fish. Data provided evidence of broad scale changes in benthic communities that can be directly related to fishing, and is likely to have important implications for ecosystem management and the development of sustainable fisheries.
- The predictions tested have important ecological ramifications for changes in structure and function of benthic communities. For example, fishing disturbance is unlikely to affect adult animals that live deep within the sediment; such species are often important in biogenic sediment modification. However, juvenile stages living nearer to the sediment surface can be directly affected, and in the long term this results in lower densities of adults.

Conclusions

- The current knowledge base is in stark contrast to knowledge of the environmental effects of land-based industries that directly use the marine environment for waste disposal or directly release substances into it. We rely on natural productivity and ecosystem function to sustain our fisheries resources, but a far higher level of assessment of environmental costs is required under the 1996 Fisheries Act.

- We have been destroying the carrying capacity of the habitat to support fisheries by removing the organisms that provide shelter for little fishes. It can be argued that the destruction of marine habitat is equivalent to clear-cutting forests on land.
- The potential importance of changes in benthic communities due to habitat disturbance by commercial fishing is often discounted because impacts have not been well documented. This study proves that fishing is changing seafloor communities, in particular by decreasing biodiversity and habitat complexity. The consequences of this have economic, environmental and social impacts.
- Determining degrees of impact to ecosystems, as well as the time scales of impact, will both lead to better determination of the ecological constraints needed for sustainable management. The weight of evidence should be of concern to resource managers. There are management strategies that could be employed that will provide some safeguards for these seafloor ecosystems. In turn, this process will help us to objectively weigh social and economic demands against biological constraints within which a sustainable fishery must operate.
- It is important that both resource users and managers become proactive about gathering appropriate data to enable risk assessment. A sustained commitment to data collection is necessary if we are to determine appropriate time scales over which to assess effects. This will help us to objectively weigh social and economic demands against the biological constraints within which a sustainable fishery must operate.

10 Programmes by Category of Funding

10.1 Summary of Funding by Provider

	Funding Year					Total
	93/94	94/95	95/96	96/97	97/98	
Funding						
NIWA	$ 2 155	$ 2 717	$ 3 119	$ 3 241	$ 3 817	$ 15 049
Cawthron	$ 305	$ 752	$ 832	$ 861	$ 951	$ 3 701
Crop & Food	$ 1 284	$ 1 275	$ 1 353	$ 1 615	$ 1 632	$ 7 159
ESR	$ -	$ 279	$ 243	$ 273	$ 273	$ 1 068
Universities	$ -	$ 337	$ 344	$ 305	$ 305	$ 1 291
Other Providers	$ 51	$ -	$ 296	$ 396	$ 451	$ 1 194
Total Funding	$ 3 795	$ 5 360	$ 6 187	$ 6 691	$ 7 429	$ 29 462
Funding as % Total						
NIWA	57%	51%	50%	48%	51%	
Cawthron	8%	14%	13%	13%	13%	
Crop & Food	34%	24%	22%	24%	22%	
ESR		5%	4%	4%	4%	
Universities		6%	6%	5%	4%	
Other Providers	1%		5%	6%	6%	
Total Funding	100%	100%	100%	100%	100%	
Programmes						
NIWA	5	10	12	13	14	54
Cawthron	2	6	5	5	6	24
Crop & Food	3	5	5	5	5	23
ESR		1	1	1	1	4
Universities		3	3	2	2	10
Other Providers	1		2	3	3	9
Total Programmes	11	25	28	29	31	124
Average Programme Size						**Mean**
NIWA	$ 431	$ 272	$ 260	$ 249	$ 273	$ 297
Cawthron	$ 153	$ 125	$ 166	$ 172	$ 159	$ 155
Crop & Food	$ 428	$ 255	$ 271	$ 323	$ 326	$ 321
ESR		$ 279	$ 243	$ 273	$ 273	$ 267
Universities		$ 112	$ 115	$ 153	$ 153	$ 133
Other Providers	$ 51		$ 148	$ 132	$ 150	$ 120
Average Programme Size	$ 345	$ 214	$ 221	$ 231	$ 240	$ 238
Competitiveness						
Bids Rejected as % Total	48%	22%	36%	36%	NA	35%
Number of Bidders	4	6	8	8	8	7

10.2 Programmes by Provider

Organisation	Year	Old O/P	Short Title	Contract	93/94	94/95	95/96	96/97	97/98
Crown Research Institutes									
NIWA	93	10	Marine Natural Products	C01201	193	193			
NIWA	95	S08	Marine natural products - resource & sus develop.	C01506			174		
NIWA	96		Marine Natural Products - Sustainable Production	C01606				228	228
NIWA	93	10	Salmon biology and population dynamics	C01203	310	310			
NIWA	93	10	Freshwater Aquaculture	C01313	96				
NIWA	93	10	Fish production in rivers and estuaries	C01314	1181				
NIWA	94	10	Species and stocks for freshwater aquaculture	C01407		152	45	45	
NIWA	94	10	Breeding and enhancement of rock lobsters	C01408		200	200	200	200
NIWA	94	10	Fisheries production in lowland lakes and estuaries	C01409		638			
NIWA	94	10	Taiapure in Effective Manag. of Recreat. Fisheries	C01410		73			
NIWA	94	10	Sustainability of cultured and enhanced fisheries	C01431		208			
NIWA	95	S08	Salmon Population Structure and Broodstock Dev.	C01501			462	462	462
NIWA	94	10	Fishing: effects on marine ecosystems and resource sustainab	C01429		159			
NIWA	95	S08	Fishing - effects on marine ecosys. and resource sus.	C01502			159	159	159
NIWA	94	10	Remote Sensing of Fisheries	C01430		235			
NIWA	95	S08	Remote sensing of fisheries	C01503			235	235	235
NIWA	95	S08	Sustainability of Cultured Shellfisheries	C01504			187		
NIWA	96		Sustainability of Cultured Shellfisheries	C01604				250	250
NIWA	95	S08	Sustainability of Freshwater Eel Fisheries	C01505			638		
NIWA	96		Sustainability of Freshwater Eel Fisheries	C01605				638	638
NIWA	95	S08	Diet and Demography of S Buller's Albatrosses	C01507			217	217	217
NIWA	95	S08	Diseases of Marine Molluscs	C01524			74		
NIWA	96		Diseases of Marine Fish and Shellfish	C01607				75	100
NIWA	95	S08	Biological Studies for enhance. of paua population	C01525			179		
NIWA	96		Enhancement of Paua Populations (Haliotis spp.)	C01608				133	133
NIWA	96		Impact on Multispecies Fisheries	C01609					274
NIWA	96		Flatfish Aquaculture Development	C01610					250
NIWA	96		Management of Taiapure & Mahinga Mataitai Areas	C01639				50	122
MFISH	93	10	Marine Aquaculture and Enhancement	MAF301	375				
MFISH	94	10	Marine Aquaculture and Enhancement	MAF401		549	549	549	549
Total NIWA					**2 155**	**2 717**	**3 119**	**3 241**	**3 817**
Cawthron	93	10	Toxic and Noxious Micro-Algae	CAW301	140	140	216		
Cawthron	96		Toxic and Noxious Micro-Algae:	CAW601				240	240
Cawthron	93	10	Microbes in Aquaculture	CAW302	165	165			
Cawthron	95	S08	Paua Larval Settlement	CAW501			182	182	182
Cawthron	94	10	Gymnodinium	CAW401		76			
Cawthron	94	10	Aquaculture	CAW402		108	138	138	101
Cawthron	96		Biochem - Perna Canaliculus Larval Viability	CAW402					90
Cawthron	94	10	Aquaculture of Undaria: culture facility/seed supply	CAW403		106	106		
Cawthron	96		Aquaculture of Undaria	CAW602				111	148
Cawthron	94	10	Energetics model for growth of drift-feeding brown trout in	CAW404		157			
Cawthron	95	S08	Trout Energetics and agricult.degradation of rivers	CAW502			190	190	190
Total Cawthron					**305**	**752**	**832**	**861**	**951**
Crop & Food	93	10	New Technologies For Fisheries Production	C02219	361				
Crop & Food	93		Fish Processing Products		556				
Crop & Food	94		Seafood quality enhancement		367	367	367		
Crop & Food	94	10	Seafood Harvesting Technology	C02418		210			
Crop & Food	95	S08	Seafood Harvesting Technology	C02521			168		
Crop & Food	96		Microbiological Safety of Seafoods	C02406		267	387	540	557
Crop & Food	96		Improv. Stability and Funct. Prop.of NZ Seafood	C02407		250	250	351	351
Crop & Food	96		Seafood Processing Science	C02502		181	181	181	181
Crop & Food	96		Mechanisms of Autolysis in Fish	C02622				400	400
Crop & Food	96		Improving Post-Harvest Crustacean Quality	C02623				143	143
Total Crop & Food					**1 284**	**1 275**	**1 353**	**1 615**	**1 632**
ESR	94	10	Marine Biotoxins: Analysis and Characterisation	C03402		279			
ESR	95	S08	Marine Biotoxins: Analysis and Characterisation	C03501			243		
ESR	96		Marine Biotoxins: Analysis and Characterisation	C03602				273	273
Total ESR						**279**	**243**	**273**	**273**
AgResearch	95	S08	Shellfish and Algal Toxins	C10541			236		
AgResearch	96		Immunoassays - Marine Algal Toxins/ Toxic Algae	C10647				236	236
IGNS	95	S08	Productivity of Marine Fish and Shellfish	C05503			60		
HortResearch	96		Viruses of Shellfish	C06635				110	110
Total Other CRIs							**296**	**346**	**346**
Private Organisations									
Proc. Des & Control	93	10	Rock Lobster Feed Development	PDC301	51				
Mont Watson	96		Management of Taiapure & Mahinga Mataitai Areas	MWL601				50	105
Total Private Organisations					**51**	**0**		**50**	**105**
Universities									
Auckland	94	10	Molecular Probes for Toxic Phytoplankton	UOA409		148			
Auckland	95	S08	Molecular Probes for Toxic Phytoplankton	UOA503			154		
Auckland	96		Molecular Probes for Toxic Phytoplankton	UOA602				163	163
Canterbury	94	10	Bio Marine Natural Products: Targets for Aquacult.	UOC404		60			
Canterbury	95	S08	Bio Marine Natural Products: Targets for Aquacult.	UOC503			48		
Canterbury	94	10	Genetic Improvement of NZ Salmon and Abalone	UOC405		129			
Canterbury	95	S08	Genetic Improvement of NZ Salmon and Abalone	UOC504			142		
Canterbury	96		Genetic Improvement of New Zealand Salmon	UOC603				142	142
Total Universities						**337**	**344**	**305**	**305**

10.3 Programmes by Category of Funding

Organisation	Short Title	Contract	Funding ($ 000) 93/94	94/95	95/96	96/97	97/98	Subcontract
Development of Aquaculture								
NIWA	Fisheries production in rivers, lakes and estuaries	C01314, 1409	1 181	638				
MAFFISH	Marine Aquaculture and Enhancement	MAF301, 401	375	549	549	549	549	
NIWA	Species and stocks for freshwater aquaculture	C01313, 1407	96	152	45	45		
IGNS	Productivity of Marine Fish and Shellfish	C05503			60			
NIWA	Salmon Biology, Population Structure and Broodstock Dev.	C01203, 1501	310	310	462	462	462	
Cawthron	Paua Larval Settlement	CAW302, 202, 501	165	165	182	182	182	
NIWA	Biological Studies for Enhancement of Paua Populations	C01525, 1608			179	133	133	UoA, C&F
NIWA	Marine Natural Products (Drugs)	C01201, 1506, 1606	193	193	174	228	228	UOC
Canterbury	Bioactive marine products: targets for aquaculture	UOC404, 503		60	48			
Proc. Des & Control	Rock Lobster Feed Development	PDC301	51					
NIWA	Breeding and Enhancement of Rock Lobsters	C01408		200	200	200	200	
Cawthron	Aquaculture of Bivalves	CAW402		108	138	138	191	
Cawthron	Aquaculture of Undaria (seaweed)	CAW403, 602		106	106	111	148	
NIWA	Flatfish Aquaculture Development	C01610					250	
Aquaculture			**2 371**	**2 481**	**2 143**	**2 048**	**2 343**	
Hazard Control								
Cawthron	Toxic and Noxious Micro-Algae	CAW301, 601	140	140	216	240	240	
Cawthron	Gymnodinium	CAW401		76				
ESR	Marine Biotoxins: Analysis and Characterisation	C03402,3501,3602		279	243	273	273	CAW
Auckland	Molecular Probes for Toxic Phytoplankton	UOA409		148	154	163	163	
AgResearch	Shellfish and Algal Toxins, Immunoassays	C10541, 10647			236	236	236	CAW
Crop & Food	Microbiological Safety of Seafoods	C02406		267	387	540	557	
Hazard Control			**140**	**910**	**1 236**	**1 452**	**1 469**	
Resistance to Disease								
NIWA	Diseases of Marine Fish and Molluscs	C01524, 1607			74	75	100	
HortResearch	Viruses of Shellfish	C06635				110	110	
Genetic Improvement								
Canterbury	Genetic Improvement of NZ Salmon and Abalone	UOC405, 504, 603		129	142	142	142	
Sustainability of Fisheries								
NIWA	Sustainability of Cultured Shellfisheries	C01431, 1504, 1604		208	187	250	250	UOC
NIWA	Sustainability of Freshwater Eel Fisheries	C01505, 1605			638	638	638	Lin,MafFish
NIWA	Effects of Fishing on Marine Ecosystems	C01429, 1502		159	159	159	159	
NIWA	Impact on Multispecies Fisheries	C01609					274	
Sustainability of Fisheries			**-**	**367**	**984**	**1 047**	**1 321**	
Seafood Harvesting								
NIWA	Remote Sensing of Fisheries	C01430, 1503		235	235	235	235	MafFish
Seafood Processing								
Crop & Food	New Technologies For Fisheries Production	C02219	361					
Crop & Food	Fish Processing Products		556					
Crop & Food	Seafood Quality Enhancement		367	367	367			
Crop & Food	Seafood Harvesting Technology	C02418		210	168			
Crop & Food	Improv. Stability and Funct. Prop.of NZ Seafood	C02221, 2407		250	250	351	351	
Crop & Food	Seafood Processing Science	C02502		181	181	181	181	
Crop & Food	Mechanisms of Autolysis in Fish	C02622				400	400	UOC
Crop & Food	Improving Post-Harvest Crustacean Quality	C02623				143	143	
Seafood Processing			**1 284**	**1 008**	**966**	**1 075**	**1 075**	
Taiapure Fisheries								
NIWA	Taiapure in Effective Management of Rec. Fisheries	C01410		73				
NIWA	Management of Taiapure & Mahinga Mataitai Areas	C01639				50	122	
Mont Watson	Management of Taiapure & Mahinga Mataitai Areas	C01639				50	105	Hauraki Maori
Other								
Cawthron	Impact of Agricultural Degradation of Rivers on Trout	CAW404, 502		157	190	190	190	Otago Reg C.
NIWA	Diet and Demography of S Buller's Albatrosses	C01507			217	217	217	MuseumNZ
Total Funding			**3 795**	**5 360**	**6 187**	**6 691**	**7 429**	

11. Summary of TBG and NSOF Support in Output 6

Type of Funding	Provider	Category of Research	Funds ($'000)	
NSOF				
	AgResearch	Hazard Control	$	174
	Crop&Food	Seafood Processing	$	11
		Other	$	57
	NIWA	Devopment of Aquaculture	$	292
		Hazard Control	$	140
		Seafood Harvesting	$	140
		Resistance to Disease	$	40
		Other	$	20
Total NSOF			**$**	**874**
TBG Co-operative Research				
	Cawthron	Development of Aquaculture	$	666
	Universities	Development of Aquaculture	$	308
	Other	Development of Aquaculture	$	401
Graduate Research				
		Development of Aquaculture	$	208
		Seafood Processing	$	11
Fellowship				
	NIWA	Development of Aquaculture	$	61
Total TBG			**$**	**1 655**

Source: *Research Report 1996/97, FRST*